AGROECOLOGY

A science and agriculture practice for small-scale farmers in sub-Saharan Africa

Kim Schneider




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ANTENNA FOUNDATION

ABOUT THE AUTHOR

Kim Schneider works for the Antenna Foundation as project manager, technical consultant and head of the agroecology unit. Kim holds a master's degree in agricultural sciences from the Swiss Federal Institute of Technology Zurich (ETHZ), specialising in African agricultural systems, soil science and agroecology. During his studies, he participated in studies on sustainable soil management in Madagascar, Côte d'Ivoire, Burkina Faso and Kenya.

He joined Antenna Foundation in 2018, where his first role was to design sustainable productive agroecosystems for different geographical and climatic regions of Africa. He then partnered with local organisations in sub-Saharan Africa to create didactic agroecological farms based on the designed agroecosystems. These farms were created to test and improve production models, as well as to promote agroecological practices among local farmers. Over the past 5 years, he has led local teams in Mali, Burkina Faso, Cameroon and Ethiopia and has travelled regularly to establish and monitor the success of the farms. He has written this agroecology manual as a support for courses and trainings given in parallel to the projects, especially in Ethiopia, DRC, Burkina and Guinea. The course is also given online, bringing together students from a dozen African countries.

ABOUT THE ANTENNA FOUNDATION

The Antenna Foundation, based in Geneva, is a non-profit foundation under Swiss law, recognised as being of public utility, created in 1989 by Denis von der Weid. Its purpose is to promote research, development, dissemination and implementation of scientific, technological and economic solutions to meet the essential needs of populations, particularly the poorest, according to the principles of sustainable development, social justice and access to autonomy.

In collaboration with an international network of scientists, the Antenna Foundation undertakes and participates in research projects in the fields of drinking water & hygiene, agriculture, nutrition, medicine and energy. In partnership with research institutes, universities, non-governmental organisations, foundations and private companies, the Foundation develops and disseminates all relevant solutions to promote sustainable access to autonomy for populations in the satisfaction of their essential needs.

The activities of the Antenna Foundation's Agroecology Unit focus on research, development and dissemination of sustainable agroecological production systems and on food self-sufficiency.

Author: Kim Schneider

Proofreading: Kim Schneider, Abebe Nigussie

Translation: Dini Egal, Kim Schneider, Benoit Hayman

Illustrations: Johanne Martin, Susana Lauer

Photos: Geronce Loick Otomé, Julian Tugwell,
Kalifa Zida Wend-Dolea, Albert Dembele, Abebe Nigussie,
Kim Schneider, Thierno Mamadou Korka Bah, Manon Renfer

Layout: Johanne Martin

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1. INTRODUCTION

Modern conventional agriculture, which emerged from the Green Revolution, facilitates the intensive production of food commodities due to use of synthetic pesticides and fertilisers, high yielding crop varieties, and mechanisation. This mode of production, although having helped sustain strong population growth over the last century, presents major environmental, health and social problems. These include water pollution, soil degradation, loss of biodiversity, global warming, dependence of producers on input suppliers, and threats to human health.

A first characteristic of modern agriculture is the predominance of monoculture. The fact that only one species is cultivated on fields of several hectares to sometimes several thousand hectares implies a very low biodiversity in these areas. A monoculture crop production results in high pests and disease incidence and thereby requires intensive use of pesticides to ensure high crop production. The soil is also depleted if the same crop is grown continiously in the same farmland, drawing on the same resources each season.

The use of pesticides is a second characteristic of modern conventional agriculture. Pesticides are products, often derived from synthetic chemistry, that kill harmful organisms in agroecosystems, such as pests, fungal diseases or weeds. Pesticides can cause soil and water pollution, health issues for farmers and consumers, and negatively impact biodiversity by killing many beneficial organisms in agroecosystems. Finally, heavy pesticide use can lead to resistance in pests, diseases and weeds, amplifying the initial problem.

Since Africa uses only 2.1 % of the pesticides produced in the world (FAO, 2021), one might think that use of pesticide is not necessarily a major problem in African agriculture. However, poor regulation, insufficient user awareness and the utilisation of particularly toxic products, sometimes banned in Europe, make the use of pesticides hazardous for the health and the environment of Africans. In addtion, commercial farms in Africa often use pesticides intensively without considering the enviromental and health impacts.

The use of mineral fertilisers is an additional feature of modern agriculture. Fertilisers are products that contain the nutrients, in mineral form, needed by the plant to sustain. They are constituted in a large proportion of nitrogen (N), phosphorus (P) and potassium (K). Their supply, in a form that can be assimilated by the crop, allows for a considerable yield increase. P and K come from mines, while N is obtained from the atmosphere through an artificial chemical process. Mineral fertilisers are not as toxic or dangerous as pesticides are. However, they can cause water pollution concerns. If too much of these nutrients are applied inappropriately, they end up in rivers, lakes and seas where they feed algae. This causes strong algal growth, leading to eutrophication – the lack of oxygen in the water due to the invasion of algae (Anderson, Bennion, & Lotter, 2014). Finally, the production of nitrogen fertilisers is energy-intensive and a source of greenhouse gases. The fixation of one kilogram of nitrogen, needed to fertilise 100 m^2 of grains, emits the equivalent of 8.6 kg of CO_2. However, the low use of mineral fertilisers in Africa, due to a lack of resources, makes these problems secondary. Problems of eutrophication of lakes are rare, and the share of greenhouse gas emissions linked to fertiliser use is minimal. The high cost of mineral fertilisers, on the other hand, makes the search for alternatives essential for many small-scale producers.

Agriculture is currently responsible for 24 % of global greenhouse gas emissions (FAO, 2016). The main drivers of these emissions are the use of fertilisers mentioned above, rice cultivation, forest and savannah fires, but above all livestock production, which accounts for 63 % of global emissions. It is therefore essential and urgent that global agricultural limits its emissions, but should African agriculture be concerned about this global problem? Africa contributes 15 % of agriculture-related emissions and accounts for 17 % of the world's population. Yet, Africa contributes only 4 % of the world's total emissions. The concern about greenhouse gas emissions can therefore be seen as a secondary problem for African agriculture, far behind the importance it might have in high-income countries.

Finally, various modern agricultural practices contribute to soil degradation. Erosion is a major concern, particularly in the tropics where rainfall is heavy, intensified by poor practices such as inappropriate ploughing, monoculture and lack of soil protection measures. Other causes of soil degradation include compaction, linked to the use of heavy machinery, and salinisation, linked to poorly managed irrigation. While erosion is a main degradation factor in Africa (Montana-rella et al., 2016), compaction and irrigation are only secondary, due to the small amount of machines and the little areas irrigated. The loss of organic matter is a crucial factor decreasing the fertility of African soils. The maintenance of soil organic matter in the tropics is a difficult process, due to its rapid decomposition in a hot and humid climate. The lack of protective measures, the soil's exposure and the low use of organic fertilisers therefore have a strong impact on soil fertility.

Developing new approaches to food production – such as agroecological practices – is therefore urgently required in Africa to reduce smallholder farmers dependence on synthetic inputs, increase food production without exploiting the natural resources, and ensure farmers resilience to climate shocks. Accordingly. agroecology farming practice has gained growing attention in many parts of the world as a best-bet strategy to meet the growing food demand in a changing climate without compromising nature and human health. Agroecological practices help resource-poor farmers to produce a diverse set of food products in a small surface area without the use of fertilizers and/or synthetic pesticides.

Agroecology could be an alternative to conventional modern agriculture, especially for small-scale farmers in sub-Saharan Africa. Agroecology can be defined as a scientific field, a practice and a social movement (Wezel et al., 2009). In this paper, we will discuss agroecology as a science and agricultural practice only. It is an innovative holistic approach to the sustainable and wise use of agricultural and water resources. It aims to transform the current agricultural system by providing solutions that integrate the three dimensions of sustainable development – social, economic and environmental to address the root causes of malnutrition, poverty and inequality. Agroecology can be part of the solution to achieving several of the UN Sustainable Development Goals (SDGs): no poverty, zero hunger, good health and well-being, clean water and sanitation, among others.

Agroecology is an agricultural methodology based on the knowledge of agronomy, biology and ecology. It is a rational and efficient approach to bring about the new, healthy and sustainable agriculture needed for the global ecological transition. It enables the production of healthy, high nutritional quality commodities, free of residues of products derived from synthetic chemistry. The approach aims to produce and regenerate degraded soils and environments, to promote biodiversity and to preserve the local genetic heritage.

Agroecology does not only place the ecological aspect at the heart of its process; the human aspect is at the centre of its concerns. The local knowledge of farmers is paramount, as the fundamental approach of agroecology is to strengthen the agricultural sovereignty of local farmers. Agroecology is a management system for farming practices that incorporates the social, cultural and political principles of sustainable development.

Agroecology has strong potential to improve the quality of life of African smallholder farmers. For small-scale food producers, it offers the following advantages:

- Cost reduction (pesticides, seeds, fertilisers). Agroecology works as much as possible in a closed loop. The necessary inputs are produced by the farming system itself.
- Soil conservation. Measures for soil protection and sustainable management of soil resources are integrated.
- Income diversification. Agroecological production provides a variety of crops and limits dependence on the yields of any one crop. Many crops are grown and animals are raised.
- Better resilience to climate hazards in a context of global disruption. Many of the practices proposed by agroecology allow for better water use in the system.
- Impact on health. The products are varied, of better nutritional quality and free of pesticide residues from synthetic chemistry.

The application of agroecology has the following constraints:

- High labour input required. The complexity and interaction of the different elements (trees, annuals, animals) makes mechanisation difficult.
- Complexity of production systems. The development and management of an agroecological production system requires a good understanding of the interactions between the different species that make up the system.
- Difficulty in marketing a wide range of products.
- Yields sometimes lower than in conventional farming.
- Difficulty in managing pests of certain crops (especially vegetables).

Agroecology is therefore particularly suited to small-scale food production. The area is small, labour is abundant and crop diversity is beneficial to the farmers. Agroecology has the potential to improve the standard of living of these farmers, especially those in difficulty (infertile soils, irregular or inadequate water resources, few resources). Diversity of production is less suited to cash crop farming, where farmers are often specialised in a particular crop.

This document is aimed at agronomists who are already adequately trained in the management and understanding of conventional and organic production systems. It covers the basic ecology, chemistry and agronomy needed to understand agroecological practices. It describes these practices and the reasons for them. After reading this document, the reader will be able to set up, develop and manage a sustainable productive agroecosystem: an ecosystem that can produce without external inputs and without depleting its resources.

2. SOIL FERTILITY

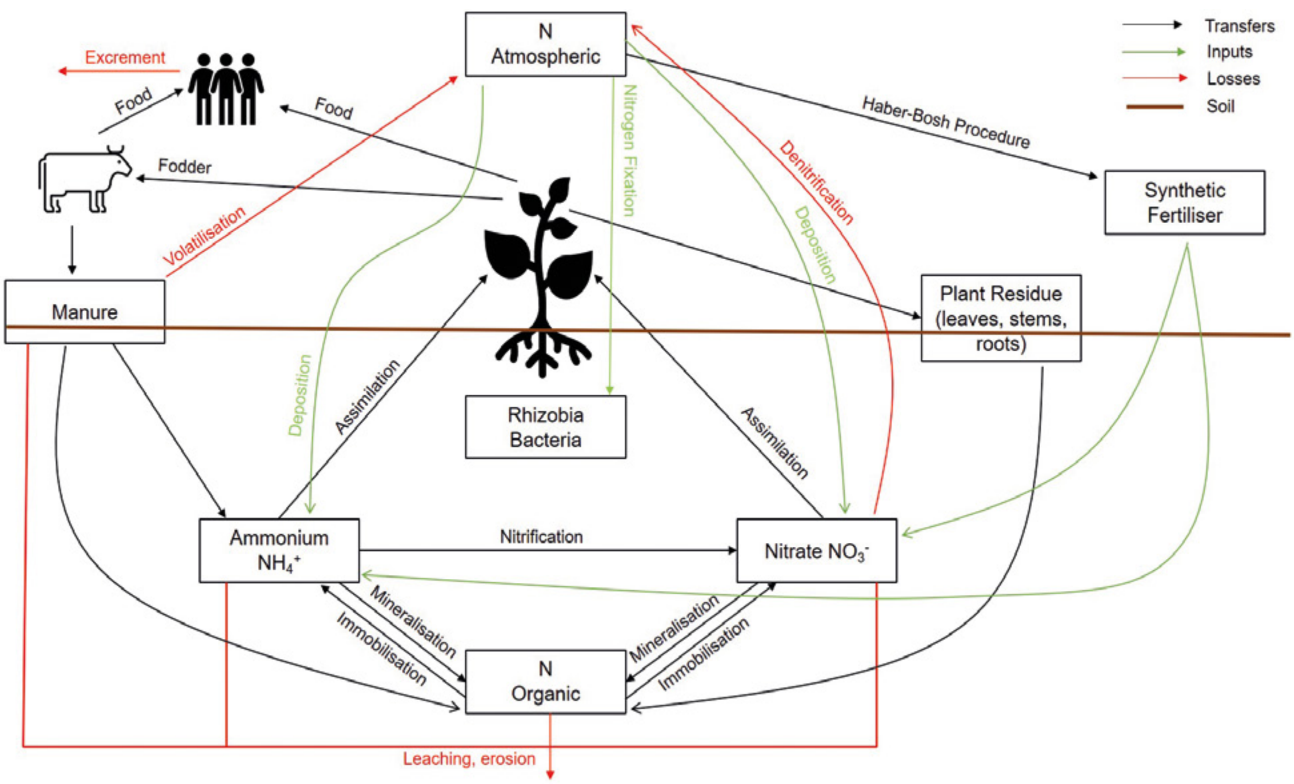
This chapter covers the basics of soil chemistry and plant nutrition necessary to understand this course and thus an agroecological production system.

2.1 NUTRIENTS

2.1.1 NITROGEN (N)

Nitrogen (N) is an essential element for most living organisms, as a component of molecules such as amino acids, proteins, vitamins and chlorophylls. Besides carbon and oxygen, nitrogen is the most abundant element in plants (McNeill & Unkovich, 2007). It is often the limiting factor for crop growth due to the high N requirements of plants and the extremely low reserves in the soil.

Nitrogen cycle



NITROGEN IN THE SOIL

The nitrogen cycle in the soil is very rapid, with nitrogen being stored in the soil for only a short time, making a constant supply essential for maintaining soil fertility. Nitrogen in the soil is found in either organic or mineral form. The organic pool contains detritus (leaves, plants, dead roots, animal secretions) and micro-organisms. The decomposition (mineralisation) of these detritus by micro-organisms releases ammonium molecules (NH_4+) which are then transformed into nitrate (NO_3^-), a process called nitrification.

In mineral form, nitrogen is found in ammonium and nitrate molecules. These molecules are mainly found in the soil solution, or bound to mineral or organic soil particles. These bonds are not strong, which explains the high availability of nitrogen in mineral form, but also the very limited retention and storage time.

Plants mainly take up nitrogen in the form of nitrate from the soil solution, secondarily in the form of ammonium.

THE IMMOBILISATION OF NITROGEN

Some soil organisms also consume nitrates and ammoniums from the soil solution, and thus immobilise nitrogen in organic form. This nitrogen is no longer available to the plant until the death and decomposition of these organisms. The C/N ratio of the amendments is therefore of crucial importance. An amendment rich in carbon (straw, manure with a lot of straw) gives energy to the soil organisms, which, in order to grow, will draw on the nitrogen reserves, which will reduce the quantity available for the plant. There is therefore an immobilisation effect caused by the supply. The immobilised nitrogen will only be available when it decomposes. The application of such an amendment does not promote the growth of the crop on which it is applied, on the contrary! It does, however, maintain the fertility of the soil and allows a more regular release of nitrogen for subsequent crops, and avoids losses through leaching and erosion. Fertiliser that is too rich in nitrogen (low C/N ratio) has the opposite effect, a priming effect: decomposition and loss of organic matter (see ch. 2.5.1).

NITROGEN LOSSES FROM THE SOIL

Soil nitrogen can leave the soil in several ways. In the event of bad practices, up to 50 or even 75 % of the nitrogen can be lost during an application (Freney, 1997).

Nitrogen can be lost from the soil to the atmosphere:

- Loss by volatilization of ammonium. Ammonium (NH_4^+) is an acid in equilibrium with its base: ammonia (NH_3), a volatile gas. Ammonium volatilization can cause significant losses if manure, slurry or droppings are mismanaged. Animal defecations are indeed very rich in ammonium. Exposure to particularly dry air causes strong volatilization which can cause the greatest losses of nitrogen supply. For this reason, animal faeces should be collected quickly and not left to dry in the sun. They must be stored in a pit covered with a tarp to avoid contact with the air. The manure applied should be incorporated into the soil to avoid contact with air.
- Under anaerobic conditions (little air, flooded plots, rice cultivation), a process of denitrification takes place. This process can be biological or chemical. It causes the reduction of nitrates (NO_3^-) to nitrogen oxides (NO, N_2O) and in dinitrogen (N2), gases that will be lost in the atmosphere.
- In the event of a fire of moderate intensity, such as during slash and burn practice, 50 to 75 % of the nitrogen in the biomass can be lost to the atmosphere (Raison, Khanna, & Woods, 1985).

Nitrogen can be lost in the lower layers of the soil and then in groundwater and watercourses:

- Loss through leaching. Water carries nitrate and ammonium molecules, and even organic molecules, into deeper soil layers or into the groundwater. Some of this can be recycled by plant roots.
- Loss through erosion. Runoff water carries nitrogen molecules and even whole soil particles off the field and into watercourses.

Some of the nitrogen is lost when crops are harvested. Food produced and sold accounts for a significant proportion of the nitrogen in the system. These nutrients are found in human urine and faeces and are rarely recycled (see ch. 4.2.2).

NITROGEN INPUTS IN THE SYSTEM

Nitrogen is mainly found in the atmosphere in the form of N2 gas. This inert gas cannot be used by the vast majority of living organisms. There are certain mechanisms that bring this nitrogen into the soil in reactive form.

- Deposition. Nitrogen in atmospheric form NH_4^+, NH_3 and NO_3^- is brought to the soil mainly by precipitation. These gases are found in the atmosphere as a result of emissions from agriculture (see next page), industry or the oxidation of N_2 during a storm. The input can be as much as 10 to 20 kg N/ha in areas where the air is heavily polluted.
- Biological fixation
- Artificial fixation

BIOLOGICAL NITROGEN FIXATION

Only certain micro-organisms living in soil or water have the capacity to reduce atmospheric nitrogen to ammonium (NH_4^+) and thus inject it into the soil-plant system. The best known bacterium for biological nitrogen fixation is the rhizobia. This bacterium forms a symbiosis with plants of the Fabaceae family (legumes), supplying them with the fixed ammonium in exchange for carbohydrates. There are many other species capable of fixing nitrogen from the atmosphere, both symbiotic and free-living organisms. These species are not exploited as much as the rhizobia-legume symbiosis in agriculture.

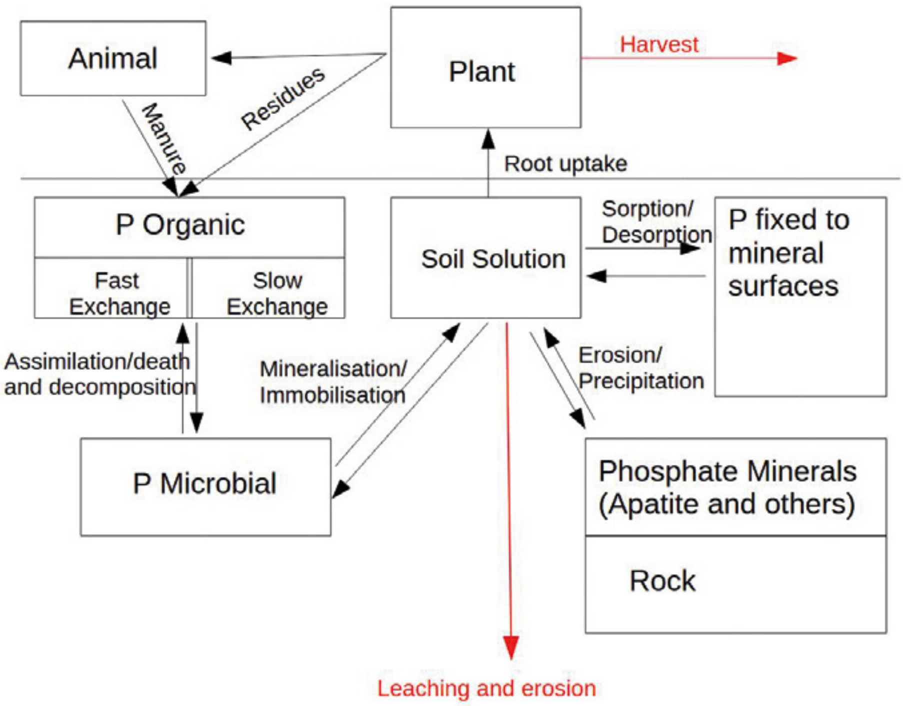
INDUSTRIAL NITROGEN FIXATION

At the beginning of the 20th century, the so-called Haber-Bosh process was invented. It allows the artificial fixation of atmospheric nitrogen into ammonium and thus the production of synthetic nitrogen fertilisers. This invention made possible a massive transfer of nitrogen from the atmosphere to the soil, which caused an unprecedented increase in yields in the industrial world. (Erisman, Sutton, Galloway, Klimont, & Winiwarter, 2008). Despite the fact that this process has enabled feeding a growing population during the last century, it has led to massive nitrogen input into agro-ecosystems, causing or exacerbating major environmental risks such as nitrate pollution of waterways, leading to eutrophication of lakes and seas (Anderson et al, 2014); the deposition of nitrogen in natural ecosystems, negatively impacting biodiversity; the production of CO_2 during this energetic nitrogen fixation, as well as the increase of N_2O emission from soils, an extremely potent greenhouse gas.

2.1.2 PHOSPHORUS (P)

Phosphorus (P) is an essential nutrient for all living organisms. Plants use it as a cellular component and for metabolic functions, such as the transfer of energy and the synthesis of organic matter (Martin & Sauer-born, 2013). Consequently, P deficiency rapidly leads to reduced growth of stems, leaves and roots (Schubert, 2017). The importance of P supply for the plant, combined with low soil availability and high demand, makes phosphorus fertilisation a necessity to maintain soil fertility and achieve sufficient yields (Scheffer et al., 2010). This is particularly essential in tropical regions, where P deficiency is one of the most limiting factors for agricultural production (Randriamanantsoa et al., 2013). P fertilisation can be done by applying primary P resources, such as rock phosphate mined and processed, or secondary P resources, such as animal manure, compost, crop residues, sewage sludge or animal bones.

Phosphorus Cycle



PHOSPHORUS IN THE SOIL

In soils, P is usually found in the form of orthophosphate (PO_4^{3-}), either in the soil solution or bound to organic or inorganic compounds. Phosphate dissolved in the solution is the only form that can be assimilated by plants. Dissolved phosphate is in equilibrium with phosphate bound to the surface of iron or aluminium oxides or clay minerals. This binding process, discussed in ch. 2.3, is particularly strong in an acidic environment, as protons facilitate specific surface complexation. The desorption of fixed phosphate is a very slow process, which makes the availability of these elements almost non-existent.

Phosphate can also be present in poorly soluble phosphate-cation structures, the phosphate minerals, e.g. calcium phosphate ($(Ca^{2+})_3(PO_4^{3-})_2$) (Apatite). In contrast to fixed phosphate, these minerals need an acidic environment to dissolve and release phosphate ions into the soil solution. This explains the low availability of P in a basic medium.

Phosphate is eventually found in organic form. Organic molecules can be degraded by micro-organisms and rapidly release assimilable phosphate. The same phenomena of mineralisation and immobilisation described for nitrogen are valid for phosphorus. Solved P is also likely to be lost through leaching or erosion. Gaseous losses of P are rare and only occur at high temperatures. A fire of moderate intensity can cause the loss of 37-50 % of the phosphorus in a system (Raison et al., 1985).

The processes mentioned are the main reasons why plant P deficiency is more often related to low P availability than to low soil P content. In fact, Martin and Sauerborn (2013) state that the P available to a plant is only 0.1 % of total soil reserves.

ASSIMILATION OF P BY PLANTS

Plants mainly assimilate P in the form of $H_2PO_4^-$ and HPO_4^{2-} from the soil solution (Schubert, 2011).

However, plants can facilitate the availability of P by dissolving it from organic and mineral pools. For instance, legumes can secrete large amounts of root exudates, such as protons, carboxylates and phosphatases, which facilitate the release of bound P and the dissolution of phosphate minerals (Hinsinger et al., 2011).

2.1.3 BASE CATIONS (K+, CA+, MG2+, NA+)

These cations are either in the soil solution, electrostatically bound (exchangeable cations) or may be components of soil aggregates, minerals or to a lesser extent organic molecules. Plants assimilate potassium, calcium and magnesium in their cationic form from the soil solution. Only exchangeable or dissolved cations are therefore available to the plant. The potassium can be fixed in a specific way, which makes its release into the soil solution very slow. Exchangeable cations, forming the CEC, are therefore of primary importance for the supply of alkali or alkaline earth metals to plants.

Basic cations form very weak single bonds (mainly Na^+ and K^+). Their presence in the center of an aggregate makes it unstable, which can easily cause it to flocculate and disperse. The destabilised aggregate is no longer attached to neighbouring particles and can therefore be washed away by run-off or infiltrating water. A fertiliser rich in basic cations, such as chicken droppings, is essential for plant nutrition but should not be overdosed as it may cause soil destabilisation, leading to severe erosion and leaching, and therefore a loss of soil fertility.

2.2 NUTRIENT UPTAKE BY PLANTS

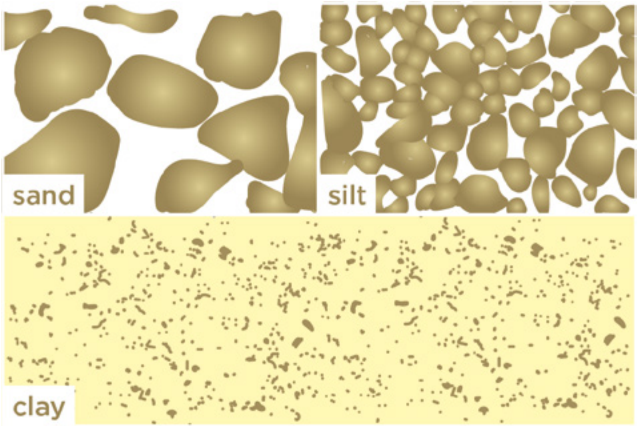
Plants get the nutrients they need from the soil solution through their roots. The soil solution is the water phase of the soil, i.e. the ion-laden water that occupies the free spaces in the soil (pores). The plant has different ways to facilitate access to the nutrients it needs:

- Increase in root surface: elongation and multiplication of roots and root hairs.
- Symbiosis with mycorrhizae (fungi) and exchange of nutrients for carbohydrates. The mycorrhizae, through their enormous network of hyphae, have access to water and nutrient reserves that are inaccessible to the plant.
- Symbiosis with rhizobia bacteria, for some plants (legumes), to obtain nitrogen (see ch. 2.5.1).
- Secretion of root exudates that modify the chemical conditions of the soil solution: protons and carboxylates acidify the solution and dissolve nutrients bound to soil particles, phosphatases dissolve phosphorus bound to soil particles.

2.3 SORPTION OF MOLECULES TO SOIL PARTICLES

The specific surface area is the size of the surface per mass of soil. It depends mainly on the size and shape of the soil particles. The smaller the particles, the more spaces there are between them, the greater the specific surface area. For this reason, clay soils have a much larger specific surface area than sandy soils. They can therefore retain nutrients and water better, as will be explained below.

Different soil particle sizes (texture) illustrating different specific surface areas.



The surfaces of soil particles in contact with water almost always carry negative or positive charges, the so-called surface charge. This charge has a permanent and a variable part.

- The permanent surface charge: this charge is linked to ions trapped inside the particle, so it is very difficult to change.
- Variable surface charge: many soil particles, especially oxides or hydroxides of different metals as well as clay particles have OH^- groups on their surface. As pH decreases, protons will bind to these OH^- groups, causing a strongly positive surface charge, whereas with increasing pH, the presence of OH^- groups will cause a strongly negative surface charge.

There is a permanent exchange of ions between the soil solution and the mineral or organic soil particles. The binding of ions to soil particles is called sorption.

- Electrostatic bonding: the charged ion is attached to the oppositely charged soil particle. As this bond is weak, the ion can be easily and quickly exchanged with an ion from the soil solution. The ions bound in this way are quickly released into the solution and can therefore be easily taken up by the plant. As the surface charge is generally negative (except in very acidic soil), it is the basic cations (K^+, NH^{4+}, Mg^{2+}, Ca^{2+}, Na^+) that are mostly bound to soil particles in this way. The capacity of the soil to provide places for the binding of these cations, and thus its capacity to supply the plant with essential base cations, is called the cation exchange capacity (CEC). CEC is an essential measure for assessing the fertility of a soil. CEC increases with increasing pH, due to the increasing negative charge mentioned above.
- Specific surface complexation: the molecule charged or not, forms a complex with a molecule on the surface. This bond can be very strong and is minimally influenced by the chemical conditions of the solution. The exchange with the soil solution is very slow, making the molecules fixed in this way minimally or not at all assimilable by the plant. Specific complexation is, similarly to electrostatic binding, pH dependent. An alkaline pH causes the fixation of metal cations (Cu^{2+}, Zn^{2+}, Mn^{2+}) and limits their availability to plants. By the same mechanism, heavy metals that are dangerous for humans or plants (Hg, Al, Pb, Cd) are fixed and do not end up in the human diet. An acidic pH, on the other hand, causes a positive surface charge, which leads to the fixation of anions, including phosphate (PO_4^{3-}), which is of crucial importance for plant nutrition (see ch. 2.1.2).

2.4 PH

The pH is the concentration of protons (H^+) in the soil solution. It is one of the most important chemical values for assessing the fertility of a soil. Tropical soils are generally acidic and, without countermeasures, tend to acidify naturally. The reasons for this acidification are as follows:

- No limestone to neutralise acidity.
- Acid rain, mainly in industrial areas.
- Creation of carbonic acid by the respiration of soil organisms.
- Secretion of acid root exudates from plants (protons and organic acids)
- Oxidation of NH_4^+ in NO_3^- (see ch. 2.1.1)

The pH has a great influence on the availability of nutrients. An acidic pH will cause:

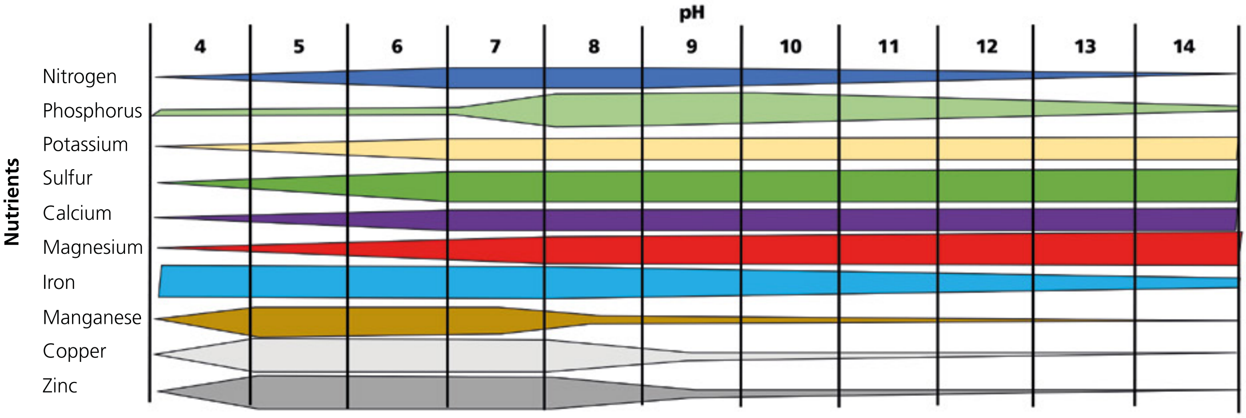
- Phosphate fixation: P deficiency.
- Saturation of the CEC by H^+ and Al^{3+} ions, deficiency in basic cations (K^+, NH^{4+}, Mg^{2+}, Ca^{2+}).
- A diminution of the CEC.
- An inhospitable environment for soil organisms.

An alkaline pH will cause:

- A fixation of essential metals, deficiency in Cu, Zn and Mn.
- A fixation of toxic heavy metals (Hg, Al, Pb, Cd).
- An increase in CEC.
- The insolubility of phosphate minerals (see ch. 2.1.2): P deficiency

The table below summarises the availability of nutrients as a function of pH. An ideal pH for agriculture is between 6 and 7. A pH below 5.5 causes serious problems with the availability of P and base cations.

Availability of nutrients according to pH



2.5 ORGANIC MATTER

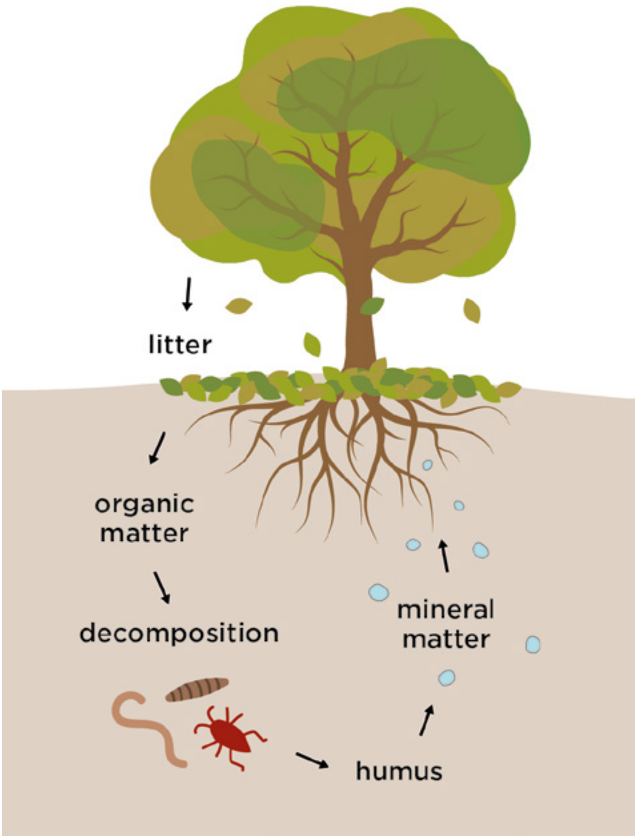
Soil organic matter is made of the organic molecules created by living organisms and is composed essentially of carbon, oxygen, hydrogen and nitrogen. It represents only a small proportion of the soil mass but is of primary importance for soil functions and plant nutrition, even if plants do not obtain their necessary carbon from it. Thanks to its very large specific surface area, organic matter provides numerous binding possibilities for organic and inorganic molecules.

It offers both predominantly negative charges, which considerably increase the CEC, and hydrophobic molecules, which allow the retention of poorly soluble molecules. Moreover, organic matter plays a central role in the creation and maintenance of a stable soil structure, through the creation of tissues and aggregates, in particular clay-humus complexes (organic matter-clay complex). In short, organic matter is an essential source of energy for soil life, both microbial and animal. These organisms are of crucial importance for the decomposition of organic inputs and thus for crop nutrition.

2.5.1 SOIL ORGANIC MATTER (SOM) DYNAMICS

The supply of organic matter to the soil is mainly achieved through the decomposition of plant biomass and animal defecation. Soil organisms (micro-organisms and arthropods) are responsible for the decomposition of litter (undecomposed OM: straw, stem, root, leaf). This organic matter, depending on its composition, can be more or less rapidly mineralised. This process releases mineral molecules into the soil solution (nitrates, phosphates, cations) and carbon in the form of CO_2 into the atmosphere. The processes of litter decomposition and SOM mineralisation are mainly dependent on humidity and temperature. In a warm, humid climate, they are very rapid, while in a drought or low temperature they stop completely. Climates with a long dry and/or cold period are therefore conducive to a build-up of SOM, which decomposes only slowly, and thus to the creation of a very fertile soil (e.g. black steppe soils in Russia). In contrast, in a hot and humid tropical climate, the process is so rapid that it endangers the preservation of SOM, if no adequate measures are taken. Moreover, exposure to air, by turning the soil over or by exposed bare soil, accelerates mineralisation.

Organic matter cycle



A fertiliser input, organic or mineral, has a significant impact on SOM. An amendment rich in carbon (mulching, manure with a lot of straw) will provide carbon to soil organisms, which will draw on the soil's nutrient reserves, mainly nitrogen, in order to grow, which will reduce the nutrients available for the plant. There can therefore be an immobilisation effect caused by the amendment. A soil amendment does not necessarly fertilise the crop to which it is applied, but maintains the fertility of the soil by increasing the SOM and improving the soil properties such as structure, porosity, and waterholding capacity.

A nitrogen-rich fertiliser application causes the opposite effect, a "priming effect": the micro-organisms have enough nitrogen available and therefore draw on the MOS reserves to feed on carbon. This causes an acceleration of the mineralisation process.

A priming effect is mostly caused by the application of a concentrated synthetic fertiliser, but can to a lesser extent be caused by the application of a nitrogen-rich organic fertiliser (Kuzyakov, Friedel, & Stahr, 2000), such as chicken droppings. The loss of SOM is also partly compensated by the supply of OM from the manure.

In summary, the risks of organic matter loss in a soil are listed below. These mechanisms, and the measures needed to prevent them, are described in more detail in ch. 3:

- Mineralization of organic matter.
- Erosion.
- Labour. Burying the litter too deep, it no longer decomposes.
- Nutrient mining of MOS.

2.5.2 C/N RATIO

The C/N ratio is the concentration of C divided by the concentration of N, i.e. [C] / [N]. This value is very important for assessing the fertility of a soil, as well as for characterising an organic amendment. This value applies to the soil itself, as well as to any organic compound, including amendments such as manure, straw, grass or compost. A high C/N ratio (C/N > 20) implies that there is a lot of carbon and little nitrogen, which can lead to nitrogen starvation. The plant will not grow well because of a lack of nitrogen. A low C/N ratio (C/N < 15) implies, on the contrary, that there is a lot of nitrogen and little carbon, which will cause an accelerated mineralization of the organic matter (priming effect) and thus a loss of fertility. A ratio of 15 < C/N < 20 is ideal, the plant's nitrogen needs are meet and there is no risk of an overly rapid mineralization of the organic matter.

3. SOIL MANAGEMENT IN SUB-SAHARAN AFRICA

This chapter aims to describe the main soils found in tropical Africa and to identify the threats that they face. Measures to protect them and maintain their fertility are discussed.

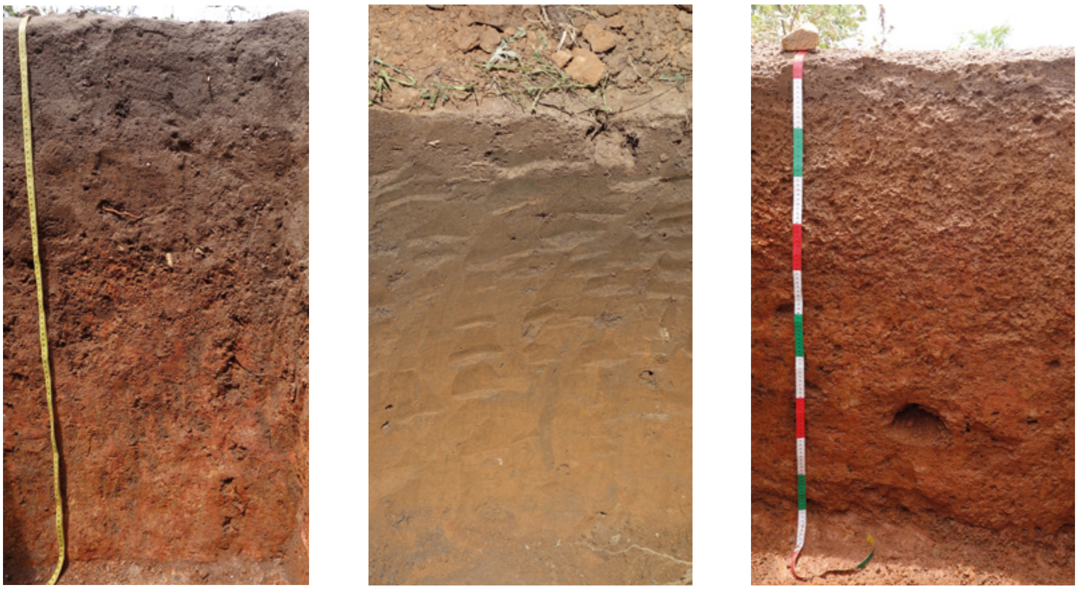
3.1 COMMON CHARACTERSTICS OF SOILS IN SUB-SAHARAN AFRICAN

The soils of the savannah and forest areas of sub-Saharan Africa have been influenced by a hot and humid climate and intensive rainfall for millennia. This has resulted in a very strong chemical and physical alteration of the parent rock and primary minerals, followed by a constant leaching of the secondary minerals produced by this process. As alkaline minerals and then basic cations were completely leached out, the soils lost their buffering capacity and became acidic. The leaching of the nutrients released from the minerals is responsible for the extreme impoverishment of these soils. These erosive processes have led to the relative accumulation of quartz, oxides and unalterable clays (ferralitic soils). These minerals do not have high surface loads and are therefore almost incapable of retaining-water and nutrients. On the contrary, many tropical soils are able to fix phosphorus and make it unavailable, P-fertilisation becoming absolutely useless.

Another typical pedogenetic process that can occur, in case of alternating dry and wet periods, is the leaching of clays into deeper horizons. The soils created (leached soils) are poor in clay at the surface, which also reduces their water and nutrient holding capacity.

Another process that can occur is the formation of iron oxide concretions: plinthites. These concretions are formed by desiccation and repeated alternation with wet periods. This process occurs in areas with a strong contrast between the dry and wet seasons, or in areas where water stagnates periodically.

The soils of the tropics: on the left a ferralitic soil (Ferralsol), in the center a leached soil (Lixisol or Acrisol) and on the right a petrified ferralitic soil (Plinthosol)



The mineral horizons of tropical soils tend to have:

- Poor water and nutrient retention.
- Low CEC.
- Phosphorus fixation.
- Low nutrient content and availability.
- Low or very low pH.

Organic matter is therefore crucial for the fertility of these soils: it provides high water and nutrient retention, retains P and prevents it from being fixed by minerals; it provides a reservoir of nutrients, high CEC and a buffer against acidification of surface horizons. Maintaining, or increasing, SOM is therefore essential for the sustainable cultivation of tropical soils.

Synthetic fertilisers alone are inefficient, as the nutrients supplied will be leached (N, P, base cations) or fixed (P). Maintaining SOM is a difficult task, mainly due to the hot and humid climate (high decomposition) and heavy rainfall (erosion, leaching). In the absence of primary forest, when the soil is used for cultivation, measures must be taken to protect the soil and limit SOM losses, and organic manure must be constantly added to compensate for losses and exports. The risks to the soil, as well as measures to protect it, are discussed in the next chapter.

3.2 RISKS FOR AFRICAN SOILS

As mentioned above, loss of organic matter is a main risk for African soils, mainly due to the infertility of mineral horizons and thus the dependence on organic horizons for plant nutrition. The major risks for these soils, mostly related to organic matter loss, are the following (Montanarella et al., 2016):

- Decomposition of organic matter

  Causes:

  - Hot and humid climate.
  - Soil exposed to air (bare soil).
  - Soil turned over (ploughing, tuber harvesting, etc.) and therefore exposed to the air.
  - Application of mineral fertiliser: priming effect.
  - Absence of organic amendments: losses are not compensated

- Erosion and Leaching

  Causes:

  - Intense rainfall.
  - Low soil cover, bare soil.
  - Soil turned over → Soil structure destroyed → Loose particles carried away by water.
  - Lack of anti-erosion measures: ridges, hedges, stone barriers, drains.
  - Over-fertilisation with chicken droppings → destabilisation of soil.
  - Insufficient SOM

- Nutrient mining: nutrients taken up by the plant are not returned to the soil.

  Causes:

  - Inexistent or insufficient fertilisation

- Acidification

  Causes:

  - Natural: rain, lack of soil buffering capacity,
  - Secretion of acid root exudates from plants. Rotation with too many legumes.
  - Mineral fertilisation with ammonium or triple phosphate (acid fertiliser)
  - Lack of use of lime or chicken droppings to raise the pH.
  - Loss of organic matter (buffering capacity)

3.3 SOIL PROTECTION MEASURES

Soil protection measures aim above all to protect and even increase soil organic matter, a key element of soil fertility. They can be summarised by these 5 objectives:

1. Protect the soil and its OM from rain (leaching, erosion).
2. Protect the soil and its OM from the air (mineralisation, loss of nitrogen through volatilisation).
3. Add organic matter to compensate for losses.
4. Add nutrients to compensate for losses/exports.
5. Increase or stabilise pH to avoid acidification.

The measures discussed in this chapter help to achieve one or more of these objectives.

CROP ASSOCIATIONS (SEE CH. 7)

Crop combinations provide better soil coverage by optimising space. They make it possible to fill the gaps between the rows of a crop that is slow to start. It allows to combine crops that are demanding or dangerous for the soil (cassava, yam) with crops that protect it (creeping or covering crops). Growing trees in a field (semi-agroforestry or agroforestry) protects the soil by intercepting raindrops at several levels.

CROP ROTATION (SEE CH. 6.9)

A well-planned rotation allows the soil to be covered at all times and protected from air and rain. It allows destructive crops to be followed by regenerative crops. Soil should never be left bare! Between two crops, a fallow period is left or a green manure is sown.

On bare soil, raindrops are not slowed down and cause soil particles to disperse at the moment of impact. The loose particles are then carried away by the runoff or infiltrating water. The bare soil does not create a barrier in the path of the water running off.

GREEN MANURES (SEE CH. 4.3)

Green manures produce a large amount of biomass, which is then returned to the soil as mulch, compost or manure after feeding animals. This input is rich in nutrients and organic matter.

MULCHING

Mulching provides soil cover between crop rows. It is recommended for crops that are slow to start (e.g. maize). It also keeps the soil moist; limits weed growth and provides a refuge for many beneficial organisms (SEE ch. 6.2).

APPROPRIATE FERTILISATION (SEE CH. 4)

Crop fertilisation must correspond to crop needs to avoid nutrient mining. If nutrients are exported (sale of products), these nutrients must be compensated by external input: nitrogen fixation by legumes, carbon fixation and nutrient uptake by any plant and transformation of these biomasses into fertiliser. Mineral fertilisation alone is not enough: firstly, it will not compensate for OM losses, secondly, it will cause a priming effect and a loss of MOS.

CONSERVATIVE TILLAGE

Intensive turning of the soil as well as exposure of the soil without cover are practices that are responsible for a degradation of soil fertility through strong erosion and decomposition of organic matter. Therefore, the soil should only be worked superficially and locally where the seed or seedling will be planted. This is facilitated by a soil without a hardened crust. A permanent cover of the soil, either by a crop or by a mulch laid on the soil, is therefore essential to prevent the creation of the crust, while protecting the soil from erosion.

No-till makes it difficult to control weeds without the use of herbicides. In an organic production system, it is advisable to keep the intensity of tillage to a minimum, but it is very difficult to do so without ploughing. Ploughing should be done superficially (10-20 cm), ideally by hand or by animal traction. Direct seeding is almost impossible for some tuber crops (potato, yam).

Tillage can be done in a way that limits erosion. Ridges, especially for tuber crops, can be created perpendicular to the slope, which will reduce runoff. Smaller ridges linking the main ridges can be added to stop runoff between ridges (SEE ch. 5).

HEDGE

Hedgerows, planted perpendicular to the slope, limit runoff and erosion. They also allow water and nutrients to be recycled when they are washed away. Hedgerows around plots are therefore recommended to prevent the export of material from the plot. Hedges should ideally be placed perpendicular to the slope. The steeper the slope, the closer the distance between the hedges should be. Hedges have other benefits: biodiversity, fodder production, barrier against pests and weather hazards.

BIOCHAR

Biochar is a pyrolysed organic material (combustion under lack of oxygen). Biochar is very important for maintaining soil fertility because it contains 70 % carbon in a virtually unalterable form. The use of biochar therefore provides a sustainable carbon supply over a long period of time. Biochar provides the following benefits:

- Extremely high specific surface.
- High CEC.
- High water and nutrient retention.
- Rich in base cations.
- High pH, buffer potential.

In the Amazon, remarkably fertile soils (Terra Preta) have been discovered, following a regular supply of plant char over a long period.

The initial substrate must be chosen carefully, as potential heavy metals could be concentrated in this way.

There may also be competition over the use of a substrate that could be used as food, feed or organic amendment.

ACIDITY CONTROL

The acidification of already acidic tropical soils is a major threat to the maintenance of soil fertility. The following measures must be taken to limit this acidification:

- If synthetic nitrogen fertilisers are used, nitrate (NO_3-) or urea ($CO(NH_2)_2$) fertilisers should be preferred. Avoid inputs of ammonium fertiliser (NH_4+), an acid.
- Limit the use of synthetic phosphorus fertilisers, as P is in the form of phosphoric acid.
- Favour the use of organic fertilisers, especially chicken droppings, which act as buffer.
- Protect or increase MOS.
- Apply lime.
- Do not overload rotations with legumes.

4. FERTILISATION

This chapter discusses the different ways to fertilise crops. It mainly describes organic fertilisers that can be used in organic farming and are an essential pillar of agroecology. It also describes synthetic mineral fertilisers and explains the dangers and issues associated with their use, as well as non-synthetic alternatives to mineral fertilisation. Finally, fertilization using plants is discussed in detail, the so-called green manure.

4.1 ORGANIC FERTILISATION

4.1.1 RUMINANT MANURE

Manure is an excellent fertiliser because it contains all the nutrients needed by the crop in balanced proportions. Its ease of decomposition in the tropics improves its performance as a manure. In addition, it contains a lot of organic matter. This helps to maintain soil fertility.

To obtain quality manure, the following measures are recommended:

- Store the manure in a concrete pit protected from rain to prevent water from washing away nutrients.
- Cover the manure with a tarp to prevent loss of nutrients in the form of gas (nitrogen volatilization, see ch. 2.1.1).
- Feed the animal's sufficient quality fodder (legume leaves, grass biomass, maize grain).
- Keep the animals in a pen to facilitate manure collection. Manure in the open will dry out and nitrogen volatilization will be fast.
- Immediately mix the soil with the manure when it is applied.

The C/N ratio of fresh manure is generally around 30 with straw, 20 without straw and can reach 10 after 2 to 3 months of decomposition.

4.1.2 CHICKEN MANURE

Chicken manure is similar to cattle manure in terms of increasing yields and adding organic matter. Its composition is less balanced than ruminant manure. It contains large amounts of base cations (K^+, Ca^{2+}, Mg^{2+}) that are important for plants and humans. These base cations also have the potential to reduce soil acidity, because protons in the soil solution create stronger ionic bonds than base cations, and will therefore replace them and bind to the organic matter (Blume et al., 2015). The decrease in the concentration of protons in the solution means an increasing pH, i.e. a decrease in acidity. In case of acidity problems, it is therefore advisable to apply chicken droppings. The alkaline effect of chicken droppings has been measured to be equal to 25 % of that of lime (Materechera & Mkhabela, 2002).

Chicken manure decomposes even faster than cattle manure and can therefore be used in a similar way to a mineral fertiliser. This means that it can be used at hearing of cereals and flowering/fruiting of vegetables to improve yields.

Beware that the large amount of base cations can destabilise the soil. K^+ and Na^+ cations form weak bonds, which can destabilise aggregates and cause them to leach out and be lost through erosion (Haynes & Naidu, 1998). It is therefore advisable to apply between 2 and 6 t/ha and to supplement with other amendments. More than 10 t/ha should not be applied.

Follow the same recommendations as for manure to obtain quality manure. The C/N ratio is generally between 10 and 15.

4.1.3 COMPOST

Compost provides a large amount of organic matter and nutrients and is therefore excellent for maintaining soil fertility. It is advisable to apply between 0.5 and 2 t/ha before sowing.

Compost is created from various plant wastes that are collected, piled, and decompose over time. The decomposition generates heat, which accelerates the process and kills diseases in the heap. To ensure sufficient heat to sterilise the substrate, it is important to insulate the sides of the compost. To avoid nutrient losses through leaching, the compost heap should be protected from rain. It is important to place the compost on the ground, as worms and insects need to access it.

To obtain quality compost, it is essential to follow these steps:

1. Place straw on the ground to optimise aeration (20 cm).
2. Add 10 cm of kitchen waste (low C/N) (no dead animals, especially bones, blood).
3. Add 30 cm of leafy and woody waste chopped into small pieces (high C/N) (2-5 cm). It is important to have such pieces to allow a good aeration and facilitate decomposition.
4. Water lightly to moisten.
5. Repeat points 2 to 4 until the desired height is reached.
6. Place straw on the pile.
7. Water every 3-4 days.
8. Every 10 days, turn the pile over, mixing all the layers.

Compost is ready for use when it is black and looks like soil (2-3 months). The C/N ratio depends on the raw material used, but a well-balanced mature compost has a C/N ratio of around 15.

Manure or dung can be used instead of kitchen waste or in addition to it. It is also possible to mix the compost with charcoal when the composting is finished. (SEE 4.1.4 Biochar).

4.1.4 BIOCHAR

Adding biochar to the soil greatly improves soil quality. biochar acts like a sponge. It retains water and nutrients and releases them when the plant needs them. biochar also prevents water stagnation.

Biochar can be applied in a range of 5 to 50 t/ha, the more the better (if you stay within this range). Biochar does not disappear from the soil, so there is no need to reapply it once the required amount has been incorporated.

Biochar provides very little nutrients. It is advisable to mix it with compost or manure before applying it. To create biochar, dry plant waste (maize stalks, nut shells, branches) should be carbonised.

4.2 MINERAL FERTILISATION

4.2.1 SYNTHETIC AND MINERAL FERTILIZERS

Synthetic fertilisers are produced industrially. They are usually referred to as mineral fertilizers, as they contain only nutrients in mineral (non-organic) form. However, mineral fertilizers are not necessarily synthetic, they are simply fertilizers that do not contain organic substances. These fertilisers provide nutrients that are directly available to the plant, allowing for a quick and effective effect on growth and yield. Nitrogen (N) and phosphate (P) fertilisers can greatly improve the yield of certain crops, mainly cereals and vegetables. Potash (K) fertiliser is important for vegetables such as tomatoes. The use of nitrogen on legumes is not recommended, as they can supply themselves with nitrogen through their symbiosis with rhyzobium bacteria. Nitrogen application will render this symbiosis useless and will therefore decrease the nitrogen production of the bacteria.

The ease of use and the rapid effect of these fertilisers allow a targeted application in time and space. It is advisable to apply the fertiliser

- at the foot of the crop for an effective effect;
- on wet soil, but not during rain. Preferably at the beginning of a rain-free period;
- without touching the leaves and roots, as they might get burned.

Despite the positive effects on yield, the supply of reactive nutrients will favour mineralising organisms in the soil over immobilising organisms, and thus cause decomposition of organic matter, a phenomenon known as the 'priming effect' (Jenkinson, Fox, & Rayner, 1985; Kuzyakov et al., 2000). The use of mineral fertilisers can therefore, paradoxically, cause a significant loss of fertility. They then create a vicious circle, as the loss of organic matter makes their application increasingly necessary to achieve acceptable yields.

The nutrients in mineral fertilisers are highly soluble (nitrate, ammonium, urea, phosphate). They are therefore likely to be quickly washed away during heavy rainfall, especially on soil with little organic matter and therefore there are few binding possibilities for the nutrients. In addition, many tropical soils contain iron oxides and clays that can bind phosphorus, making it unavailable to crops.

For these reasons, and particularly in the tropics where rainfall is intensive and soils are likely to bind phosphorus very strongly, it is essential to use mineral fertilisers in combination with an organic input.

In Africa, it is advisable to use urea as a nitrogen fertiliser. Ammonium fertilisers (e.g. DAP, diammonium phosphate) acidify the soil, which is problematic for tropical soils. Nitrate fertilisers are too soluble and risk being washed away too quickly by rainfall. For phosphate fertilisers, it is advisable to use TSP (Triple Super Phosphate) despite its solubility and acidity.

Synthetic fertilizers are generally not allowed in organic farming.

4.2.2 HUMAN URINE

Most of the nutrients excreted by humans are found in the urine and not in the stool. Urine contains 80 % and 55 % respectively of the nitrogen and phosphorus that humans secrete. It also contains many minerals (calcium, potassium, iron, magnesium, copper, zinc). Therefore, recycling nutrients from urine has a strong potential to replace the use of synthetic fertilizers. The urine supply will provide the plants with the nutrients they need and thus prevent soil depletion. However, as urine contains no organic matter, it must be used in combination with an organic fertilizer.

The urine of a healthy person is sterile. Pathogens are found in the stool. It is therefore essential to observe the following rules to avoid contamination:

- Urine should not come into contact with faeces.
- The urine of people who are ill or taking medication should not be used.
- Urine should be stored for at least 3 months in a closed jerry can before use.

As an alternative to the 3-month waiting period, treatment with $Ca(OH)_2$ is possible. Add 10 g of $Ca(OH)_2$ per litre of urine directly into the jerrycan. This will raise the pH of the urine to a value of 12.5. This will have the following effects:

- Inhibits urea hydrolysis, which prevents the formation of ammonium gas:
  - Limits nitrogen loss
  - Limits odour
- Kills a large proportion of any remaining pathogens in the urine.

The application of urine can be done in 2 ways:

- Mixed with organic fertilizer: After 3 months of storage in jerry cans, the urine is mixed with compost or manure ready for application. This enriches the organic fertiliser with nutrients
- Directly by watering at the foot of the crops. This allows for targeted fertilisation in space and time (as with mineral fertiliser). Since urine is very soluble, it must be applied regularly in small doses (once every 1 to 2 weeks). It is important not to wet the leaves with the urine, as the salt and ammonium could burn them. It is advisable to dilute the urine by a factor of 4 with water.

A supply of 3,000 l/ha meets the phosphorus requirements of maize. However, 20,000 l/ha are needed for nitrogen requirements. It is therefore recommended to use urine mainly for phosphorus demanding crops (legumes, cereals), at a rate between 1,000 and 5,000 l/ha.

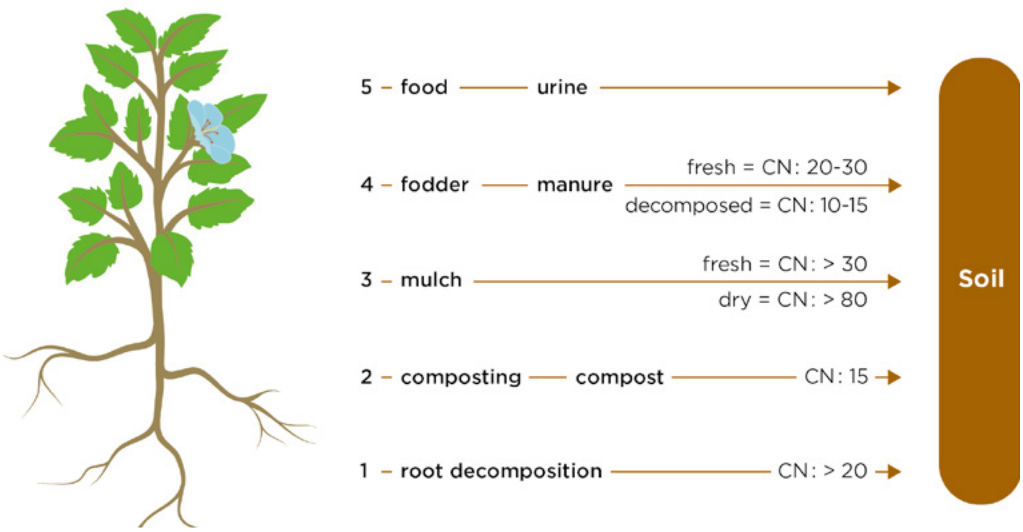
4.3 GREEN MANURE

As mentioned in ch. 2.1.1, legumes are a family of plants (Fabaceae) whose members have the specificity of forming a symbiosis with the rhizobia bacterium. The roots of legumes secrete molecules that attract the bacteria and create nodules that enclose them. The rhizobia has the ability to fix the atmospheric and almost inert gas N2 into ammonium, and pass it to the legume in exchange for carbon (McNeill & Unkovich, 2007). In the case of soils fertilised with nitrogen, the rhizobia will be considered as a parasite, since it will obtain carbon in exchange for nitrogen already supplied by the soil and therefore useless to the plant. In this case, the plant will not perform symbiosis with the rhizobia and no nitrogen will be fixed. It is therefore not advisable to add nitrogen to legumes. In addition, it is very important to have a phosphorus supply for the good growth of the plant and the efficiency of the biological fixation.

The cultivation of leguminous crops therefore allows for the supply of nitrogen from the atmosphere into the agricultural system. The transfer of nitrogen, as well as that of the mobilised nutrients and organic matter produced, then takes place via five different pathways to the soil and to the eventual target crop.

- The roots and some of the unharvested above-ground parts decompose on site after the crop has died. This decomposition enriches the soil with nitrogen, organic matter and returns the mobilised nutrients in an assimilable form.
- The plant biomass is composted and thus enriches the compost, which can be used as manure.
- The plant biomass is used as mulch. As it decomposes, it will enrich the soil of another crop.
- The biomass and/or grains are used as fodder. The mobilised nitrogen, organic matter and nutrients will therefore be found in the animal manure, which will be used for fertilisation.
- The grains are consumed by humans. The nitrogen and other nutrients are found in the urine, which, if used, can be used for fertilisation.

5 pathways to transfer nutrients



Only by passing through animals, humans or compost is it possible to produce a fertiliser that can be easily assimilated and used in a targeted manner in space/time. The decomposition of biomass directly on the soil (mulching) only enriches the soil. The time it takes for the mulch to decompose does not allow for fertilisation of the crop on which it is applied. It should also be known that plants will also mobilise certain nutrients from the soil reserves (P, K, Mg, Ca). The transformation into manure therefore allows for the supply of assimilable nutrients other than nitrogen.

4.3.1 GRAIN LEGUMES

Grain legumes (beans, peas, groundnuts, cowpeas, soybeans) produce a lot of edible grain, enrich the soil and do not require nitrogen. The grain contains important proteins for a healthy and balanced diet. To improve the performance of these plants, it is advisable to apply a phosphorus (P) supplement: manure, mineral fertiliser or human urine. Grain legumes can be used to improve soil fertility. This can be done by using the stems and leaves as mulch, using them as compost or feeding them to animals to produce manure.

Different types of grain legumes

4.3.2 GREEN MANURE: LEGUMES

Legumes can also be used for the sole purpose of enriching the soil. Some species (Desmodium, Mucuna, Stylosanthes, Perennial Groundnut, Cajan Pea) do not produce edible grains, but capture larger amounts of nitrogen in their abundant foliage. The biomass can then be used to create a manure as mentioned above.

The potential for soil enrichment is much greater with green manures than with grain legumes. It is therefore advisable to include green manures in rotations between food crops.

Stylosanthes guianensis, Stylosanthes hamata

Perennial legume (3 years), erect with lignified stems (1-1.80 m)

Common names: Stylo

Climate: Equatorial climate, savannah climate, hot semi-arid climate. Withstands dry seasons.

Soil: Many soil types, especially poor and acidified soils.

Potential: High biomass production (5-10 t/ha), no need for fertiliser, strong root system, high N fixation (70-200 kg/ha), ability to mobilise phosphorus and trace elements (B, Cu, Zn, Mn), excellent fodder (remains green in the dry season), melliferous, highly competitive, can be controlled by simple mowing at ground level.

Limitations: Slow establishment, fastidious seed harvesting, poorly tolerates overgrazing.

Management: Sowing: Sowing should be done in seedholes (7-12 seeds/seedhole), very lightly covered (< 1 cm deep) with 30-40 cm between the holes. The quantity of seed required is 2-3 kg/ha. When broadcasting, the amount needed is 5-6 kg mixed with 15-20 kg of sand. Stylosanthes can be grown as a pure crop or in association with food crops (rice, cassava, maize). Stylosanthes is not very competitive at the beginning of its growth, and weeding may be necessary for a good establishment. Stylosanthes can be mowed every 2-3 months (25 cm from the ground). It can be used as fodder for cattle, sheep, pigs and poultry. Due to the slow initial growth, stylosanthes should be cultivated for at least one season. A simple ground level mowing, preferably at the end of the dry season, removes it and leaves the soil enriched for the next crop. If a new crop is not planned, the stylosanthes can remain in place for several years. This enriches the soil and encourages the restoration of degraded soils.

Mucuna pruriens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Creeping annual

Common names: Velvet bean

Climate: Equatorial climate, savannah climate.

Soil: Medium fertile soil, tolerates acidity.

Potential: High competitiveness, fast growth (3-4 months), high biomass production (5-10 t/ha)

Limitations: Toxicity to humans and non-ruminants, presence of antinutritive substances.

Management: Sowing is done in seedholes 20-80 cm apart. Harvesting takes place 3-4 months after sowing. Ideal as a cover crop between two crops. Elimination of mucuna can be difficult without herbicides.

Desmodium intortum, desmodium uncinatum

Climate: Equatorial climate, savannah climate, hot semi-arid climate.

Soil: All soil types, tolerates acidity

Potential: Pest control in cereals (see ch. 7), excellent fodder.

Limitations: Toxicity to humans and non-ruminants, presence of antinutritive substances.

Management: Sowing is done in lines 50 cm apart, sow 5 kg/ha mixed to 10 kg/ha sand. Mow every 2-3 months.

Arachis pintoï, arachis repens

Creeping perennial legume

Common name: perennial groundnut.

Climate: Equatorial climate, savannah climate.

Soil: All types of soil.

Potential: Undemanding, no need for fertilisation, high nitrogen fixation (50 kg/ha), excellent ground cover (anti-erosion), excellent weed control, good soil restructuring (ideal for restoration of degraded soils), shade tolerant (ideal cover under orchards), excellent fodder, endure overgrazing.

Limitations: Slow and difficult to establish (cuttings), little drought tolerance, difficult to eradicate.

Management: Sowing is done using cuttings (stolons or stems of 20-30 cm). Plant 2 nodes in the soil in the wet season at a density between 30 cm x 30 cm and 50 cm x 50 cm. Weed regularly for the first few weeks. Once the cover is established, the plot can be used intensively as a pasture. Perennial groundnuts are among the most nutritious tropical legumes. Eradication is difficult and requires heavy tillage, herbicide or intensive overgrazing. It is therefore advisable to install this green manure for several years.

Cajanus cajan

Bushy perennial legume (0.5-4 m)

Common names: pigeon pea, angola pea, congo pea

Climate: Equatorial climate, savannah climate, hot semi-arid climate, supports long dry seasons

Soil: All type of soils

Potential: Bush creation in a few months, high biomass and grain production, edible grains.

Limitations: Not suitable for mixtures or grazing due to bush formation.

Management: Sow directly into the soil with a distance of 35 cm between plants. For fodder use, mow the plants regularly to prevent the formation of large bushes. For seed production, sow at a density of 1 m x 1 m, let it grow and harvest the seeds after 7-8 months. Pigeon pea can be grown in hedgerows, or in association with other crops (maize, cassava).

4.4 GREEN MANURE: LEGUMINOUS TREES

Leguminous trees (Gliricidia, Sesbania, Calliandra, Leucaena, Cajan Pea, Acacia) can also be planted as hedges around the crops (photo opposite) and the foliage transferred using the processes explained above. The tree roots will be able to draw water and nutrients from deeper layers. Leguminous hedges provide a quick protective hedge (against climatic hazards and pests), as well as fodder production, mulching and nitrogen transfer from the atmosphere to the fields. Foliage and seeds of leguminous trees are very good fodder.

4.5 GREEN MANURE: GRASSES

Grasses can also be used as green manures. These plants (with the exception of eleusine) will not fix nitrogen but will restructure the soil, increase the organic matter content of the soil (through a high production of biomass, thus a high fixation of carbon by photosynthesis). Grasses will mobilise soil nutrients (phosphorus and trace elements). However, the C/N ratio of grasses is much higher (fresh: C/N between 40 and 60, dry between 60 and 100), so caution must be taken to avoid nitrogen starvation when applying as a mulch.

Brachiaria ruzuzuiensis, B. brizantha, B. decumbens, B. humidicola

Erected C4 perennial grass (1-1.50 m)

Climate: Savannah climate, hot semi-arid climate, supports long dry seasons.

Soil: All types of soil, tolerates acidity.

Potential: High biomass production, good forage quality, weed suppression, strong and deep root system allowing recycling of nutrients and water from lower layers, ability to extract phosphorus, ability to decompact and restructure soil, ideal for regeneration of degraded soils. Potential for pest control in cereal crops (see ch. 7.2.2)

Limitations: Difficulty in eradicating brachiaria for recultivation. Important not to let brachiaria germinate if recultivation is to be carried out.

Management: Seedholes (8-10 seeds) or cuttings spaced 30-40 cm apart, 3-7 kg/ha required, broadcast: 10-20 kg/ha. The brachiaria is mown every 2-3 months, it can be used as fresh fodder, grazed or dried and used as hay. Eradication requires ground level mowing, overgrazing or intensive tillage. Brachiaria can be planted as a hedge, or as a plot divider, which eliminates the problem of eradication.

Pennisetum purpureum

Erected C4 perennial grass (1-1.50 m)

Climate: Savannah climate, equatorial climate

Soil: All types of soil.

Potential: High biomass production, good forage quality, weed suppression, strong and deep root system deep root system for recycling nutrients and water from lower layers, ability to mobilise phosphorus. Potential to control pests in cereal crops (see ch. 7.2.2)

Limitations: Difficulty in eradicating Pennisetum for recultivation.

Management: Seedholes (8-10 seeds) or cuttings spaced 30-40 cm apart 3-7 kg/ha required, broadcast: 10-20 kg/ha. Pennisetum is mown every 2-3 months, it can be used as fresh fodder, grazed or dried and used as hay. Eradication requires ground level mowing, overgrazing or intensive tillage. Pennisetum can be planted as a hedge, or as a plot divider, which eliminates the problem of eradication.

Eleusine coracana

Erected C4 perennial grass

Common name: Eleusine, finger millet.

Climate: Savannah climate, hot semi-arid climate

Soil: Mildly fertile soils

Potential: High biomass production (12 t/ha) in a limited time, low water requirement, high quality fodder, edible seeds, strong and deep root system allowing recycling of nutrients and water from lower layers, ability to restructure soil, ability to fix nitrogen, easy to eradicate by simple mowing.

Limitations: Photoperiodic (grows only in rainy season), not competitive, host plant for striga weed.

Management: Broadcast sowing (8-10 kg/ha). Weed regularly. Harvest (edible) seeds after 3-4 months. For fodder production, eleusine should be mown before hearing. A simple mowing at ground level is sufficient to eradicate it.

4.6 MIXING LEGUMES AND GRASSES

Depending on the purpose, duration, soil and climate, the different green manures mentioned above can be used. For fodder production or grazing, it is advisable to mix the different species. This will reduce the risk of diseases or pests, increase the nutritional quality of the fodder and optimise soil restructuring and regeneration. A legume-grass balance is essential for quality forage: legumes provide the protein that is missing in grasses, grasses provide the carbohydrates and fibre that are in low concentration in legumes. This balance is also important in the manure produced in the end (mulch, compost, manure). As explained in ch. 2, a low nitrogen fertiliser will cause immobilisation of soil nutrients, while a fertiliser that is too high in nitrogen will cause a priming effect and a loss of organic matter.

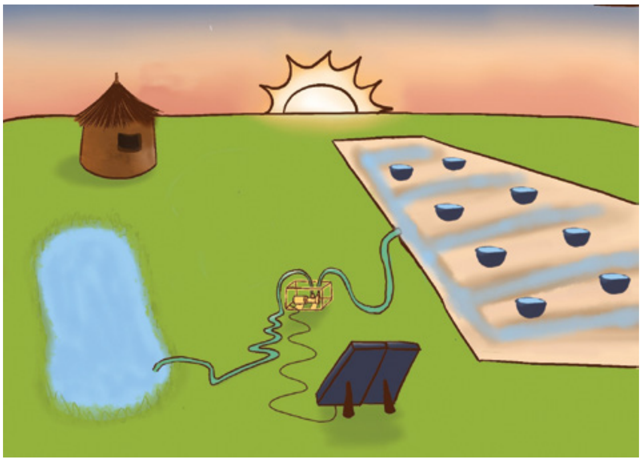
5. WATER MANAGEMENT

This chapter outlines irrigation techniques and their advantages and disadvantages. It describes the water retention practices essential in dryland farming.

5.1 IRRIGATION SYSTEMS

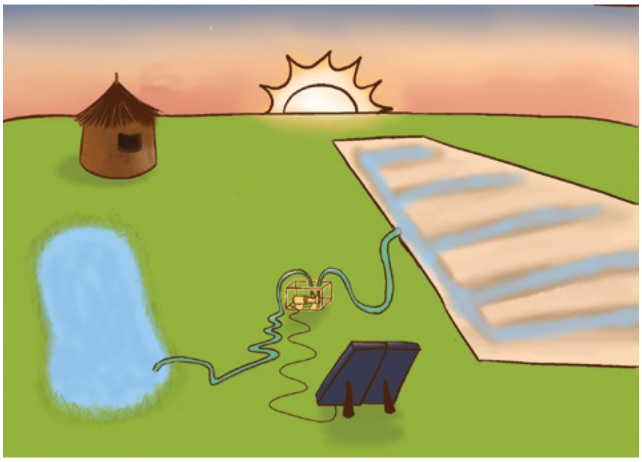
5.1.1 MANUAL IRRIGATION

Manual irrigation is the irrigation system that requires the least infrastructure and is the easiest to set up. It consists of watering the plants directly by hand, either with a hose or a watering can. This represents a very important workload but does not require any particular investment and the efficiency is high (few losses). To facilitate the work, tanks can be placed at different locations on the land and filled with a surface pump; or with the pressure of a water tower itself filled by a surface pump or by a borehole. This will greatly reduce the distances involved in irrigation. This improved system naturally requires a higher investment.



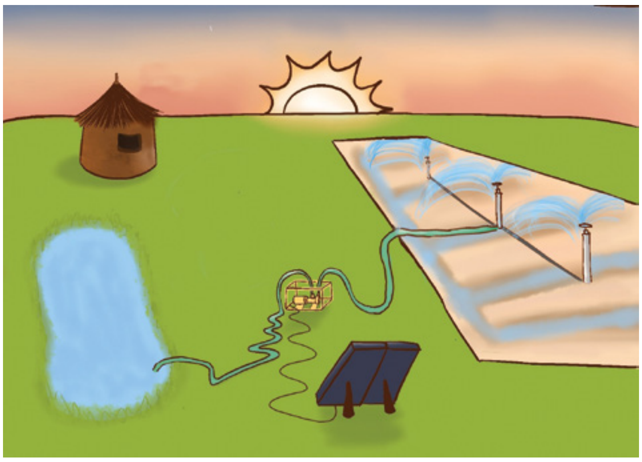
5.1.2 SURFACE IRRIGATION

Surface irrigation, or gravity irrigation, consists of irrigating plots by letting the water flow using gravity. Channels are created to bring the water to the crop. The crop is usually grown on ridges and the water flows through the furrows. This irrigation system requires little equipment depending on the morphology of the land and the type of water supply. A water tower or high water tank is needed, as well as a means to fill it (surface pump, borehole). The major investment is to create the canals and furrows, which is a lot of work but does not require special equipment. The work of irrigation is then less, it is enough to open the valves to irrigate the plot. The concern with this system is the low irrigation efficiency, which varies between 25 and 60 %, meaning that 75-40 % of the water applied is lost and not used by the crop.



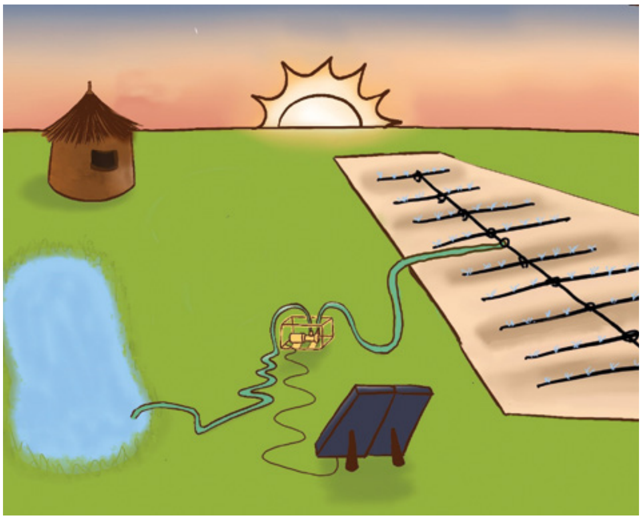
5.1.3 SPRINKLER IRRIGATION

This system of irrigation consists of applying water on the crops with sprinklers. The investment is higher because sprinklers and extensive piping must be purchased, in addition to a water tank (water tower, retention basin) and a means of filling or pumping water directly. The work to install and operate is limited and the efficiency is better than surface irrigation (60-80 %). The concern is that this system wets the plants heavily, which encourages disease development. Irrigation in windy conditions is also a problem, as losses will be very high. This system is optimal for sandy soils.



5.1.4 DRIP IRRGATION

This is the most efficient irrigation system (80-95 %) because it delivers water directly to the feet of the plants in a regular manner. The plant can therefore draw the water directly before it leaches. The cost of installation is significant as there is a lot of piping to be installed, as well as a water tank (water tower, retention basin) and a means of filling it or pumping the water directly. Installing the system requires some work and moving it is not easy. The equipment can quickly deteriorate (e.g. clogged drippers). Drip irrigation can also lead to poor root development of plants, if not applied correctly (see 5.2 Good irrigation practices). However, the workload to irrigate is minimal, water losses are insignificant and it is possible to water at any time. Finally, the plants do not get wet, which limits the spread of diseases. This system is not ideal for sandy soils where the water from the drippers will irrigate only locally (poor horizontal dispersion through the sandy soil).



5.2 GOOD IRRIGATION PRACTICES

Various measures can be taken to optimise irrigation and limit water losses.

- Water in the evening and in the morning when temperatures are low, which will limit evaporation and thus optimise irrigation efficiency.
- Do not water during the day. Fresh water on the plant during hot weather can cause stress that injure or kill the plant.
- Water according to the needs of the plant and the season. Always adapt the irrigation time to the crop, temperature and rainfall.
- Avoid wetting the aerial parts. This will limit the development of diseases. Drip and surface irrigation should not wet the plants. When watering by hand, good practice can greatly limit the problem. Sprinkler irrigation does not keep plants dry.
- Limit irrigation at the first plant stages to promote root growth. After transplanting vegetables, for example, it is advisable to leave a few days without irrigation. This will force the plant to develop roots. It is especially important to do this if drip irrigation is chosen. This system may prevent the plants from developing roots because water is supplied regularly to the feet of the plants.
- Use water retention measures to limit evapotranspiration and erosion (see 5.3 Water retention techniques).

5.3 WATER RETENTION TECHNIQUES

In dry areas, many water retention techniques exist and are useful for optimising irrigation and limit water requirements. These techniques are specially useful for rainfed crops

5.3.1 SOIL COVER

Good soil cover, with mulch and dense crops at all times, helps to retain water in the system, limiting evapotranspiration and protecting the soil from rain erosion. Water will no longer run off, but will be retained for later use by the crops.

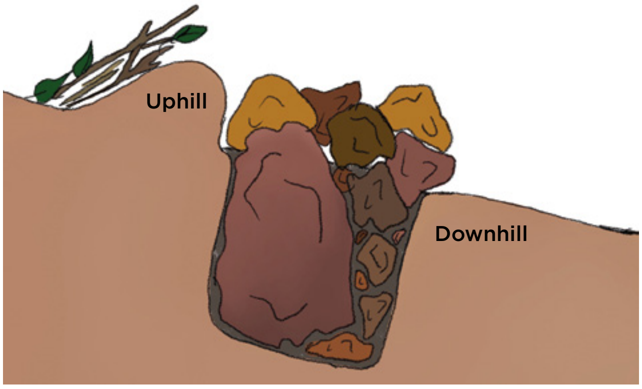
Mulch to cover ridges in Burkina Faso

5.3.2 RIDGES (SEALED OR UNSEALED)

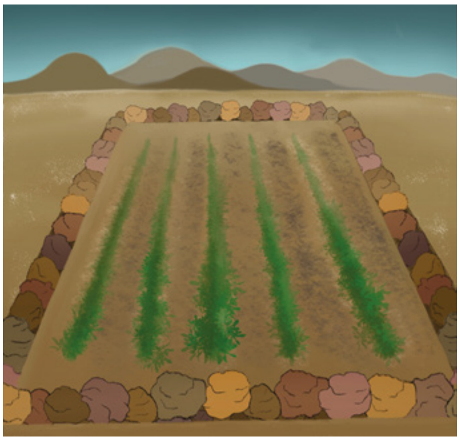
Water will be retained between the ridges and the plant roots will be able to access it. In the furrows, water-intensive crops can be grown or paths can be left. In the ridges, crops are grown whose fruit/tubers/roots are underground so that the edible product does not rot if water stagnates. Depending on the species, the ridges can be between 20 and 50 cm high. In the rainy season, it is advisable to make the ridges higher and plant the crops on them. In the dry season, ridges can be added perpendicularly, to retain water more effectively. This should only be done in the dry season, otherwise the water will stagnate excessively.

Sealed ridges in Burkina Faso

Stone barriers



Field encircled by stone barriers



5.4 STONE BARRIERS AND HEDGES

Around the plot, hedges help to retain water. Hedges prevent heavy flooding and retain water on the plot. In addition, a trench 30 cm deep and wide can be dug and filled with stones up to 10-20 cm above the ground. This increases water retention and reduces the risk of erosion. Stone barriers can also be created between individual plots.

5.5 FIELD BELTING

Separating plots with vegetation belts also optimises water retention in these plots and limits erosion. It is possible to separate these plots with rows of fodder grasses or fast-growing leguminous trees (pigeon peas), which can be harvested as fodder, or with rows of pineapples, which are very effective against erosion. Other species can of course be considered for the belts.

Examples of belting with brachiaria grasses in Mali and with pineapples in Cameroon:

5.6 CONTOUR LINE LAYOUT

The contour line layout principle is very effective in limiting erosion and keeping water in the plots. It consists of creating large ridges (minimum height 50 cm) along the contour lines. These ridges cross the plots. The spacing depends on the slope; the steeper the land, the closer the ridges are. Trees such as moringa are planted on the large ridges with a wide spacing, for example 5 m between plants. This will solidify the ridges, recycle infiltrated water, while only causing reduced shade.

Scheme of a contour line layout

5.7 HALF-MOONS

The half-moon technique consists of creating spaces where nutrients and water will be concentrated to optimise the growth of the plant in an dry environment. A half-moon with a diameter of 2 m and a depth of 20 cm is dug. Manure is applied to the half-moon by mixing with the loosened soil. The remaining soil is used to create a ridge on the downstream side of the half-moon. The demanding crop (cereals, vegetables, etc.) is sown in the half-moon. A less demanding crop (cowpea, groundnut, bean) can be sown on the ridge. The half-moons are spaced 4 m apart; it is essential not to cultivate the spaces between them, the objective being to collect water on a large surface and to concentrate it on the small surface of the half-moons. The half-moon technique is very interesting for cultivating degraded land and dry areas

Teaching half-moon technique in Burkina Faso

5.8 ZAÏ HOLES

This technique consists of creating holes 20 to 40 cm deep and wide, spaced 30 to 70 cm apart, which are filled with manure and soil and where crops (e.g. maize, sorghum, cowpeas) are sown. Ridges are created between each hole, in order to bring rainwater into the zaï holes. Manure and any mulch is placed directly into the zaïs holes. In this way, fertilisation and retention are targeted on the crop. The goal is the same as the half-moons, but the method is different.

Maize cultivated in Zaï holes in Mali

6. PEST AND DISEASE CONTROL

This chapter addresses the different means available in agroecology to limit pest and disease attacks. The role of biodiversity in protecting crops is explained, followed by active methods such as biofumigation, associations, rotations and natural treatments.

6.1 BIODIVERSITY: RESOURCE DISCONTINUITY

High biodiversity, both in terms of a maximum number of varieties of the same species and a maximum number of species, allows for the limitation of pest expansion through resource discontinuity and through repellent effects in some cases (see below). The principle of resource discontinuity implies that the invasion of a pest or pathogen will be limited by the fact that it will not find a suitable host. For example, combining 2 or 3 crops will slow down the spread of a fungal disease infecting only one of the crops, as the spores will have more difficulty reaching the next row of the host crop.

Crop diversity limits the risk of crop failure, as a poor harvest of one species can be compensated by a good harvest of another.

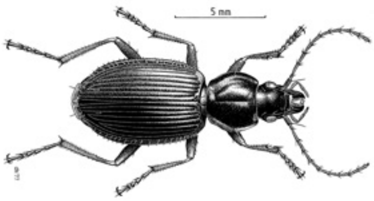
6.2 BIODIVERSITY: CONTROL BY AUXILIARIES

A high diversity of plants, combined with little or no use of pesticides, also increases the diversity of insects present in the agroecosystem. This can positively affect crop pollination on the one hand (presence of pollinators), but mainly increase the presence of beneficials. Beneficial insects, or antagonists, are predators that feed on other insects and can therefore reduce pest populations. Beneficiaries can also be parasitoid species, which lay their eggs inside the larvae of other insects, which allows the control of certain pests. Finally, beneficials can be bacteria, fungi, viruses or nematodes that infect insect pests.

A high biodiversity of plants, as on this agroecological farm in Cameroon, allows a better resilience of the production system.

6.2.1 CARABIDAE

They are large beetles (15-20 mm), mostly polypredators and considered beneficial to crops. They are found on the ground, under bark, leaves, mulch, stones etc. The larva is also predatory and rarely a pest. Mulching greatly increases the presence of these insects.



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6.2.2 STAPHYLINIDAE

Beetles whose ecology is very similar to the Carabidae, they are smaller (a few mm) and therefore hunt very small insects, aphids and nematodes.

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6.2.3 COCCINELLIDAE

Flying beetles 0.1 to 1.5 cm in size, 90 % of which are predators of aphids, whiteflies, cockroaches and leafhoppers. Coccinellidae also feed on pollen and nectar.

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6.2.4 WASPS (APOCRITA)

This suborder contains thousands of small (0.3 to 5 mm) parasitoid species. The adults feed on nectar and pollen, and lay their eggs inside other insects. The larvae then feed on the dead insect. These wasps are among the most useful beneficials in an agroecosystem.

The suborder also contains larger predatory wasps (Vespidae, Sphecidae), whose larvae feed on insects and adults on pollen and nectar.

6.2.5 OTHER INSECTS

Ants (formicidae) can be effective predators of pests. However, they can also protect some pests (aphids), which they feed on. Members of the orders Diptera (flies), Neuroptera, Heteroptera and Odonata (dragonflies) are also known as auxiliaries.

6.2.6 SPIDERS (ARANEAE)

Spiders are among the most useful beneficials of agroecosystems. All spiders are predatory and fall into two categories: those that hunt their prey and those that create webs to trap them. They feed mainly on insects. Mulching and refuges are important for the survival of spiders.

6.2.7 OTHER TYPES OF AUXILIARIES

Some mites are also predators. Many fungi, bacteria, viruses and nematodes can parasitise pests and reduce their population. However, it is difficult to notice the presence of these antagonists.

6.2.8 CONSERVATIVE BIOLOGICAL CONTROL

Conservative biological control is an approach that involves protecting and attracting antagonists into the agro-ecosystem by modifying the environment and creating a hospitable habitat for them (Martin & Sauerborn, 2013). Possible measures to achieve this are:

- Crops association: Andow (1991) synthesised the results of 200 studies, showing that 53 % of predatory species and 75 % of parasitoid species were more numerous in a field of associated crops than in a monoculture. Furthermore, 52 % of pests were less numerous in the polyculture.
- Flowers: Many beneficials, especially beetles and parasitoids (wasps), feed on pollen and nectar. Planting flowers, as a crop or as an attractive plant, will increase the presence of these species (as well as pollinators).

Flowers, such as this Marygold in Cameroun, attract beneficial insects in the agroecosystem.

- Planting hedges and stone barriers to provide refuge for beneficials and increase biodiversity by encouraging their presence.
- Permanent soil cover: through crops and extensive mulching, it will provide an ideal habitat for many soil-dwelling auxiliaries (spiders, beetles, mites).
- Adding organic matter to the soil: a soil rich in organic matter will promote the presence of soil-borne beneficials and soil-borne fungal disease antagonists.
- Avoid the use of insecticides, fungicides or antibiotics which, in addition to killing the target pest or disease, will kill the beneficials.

However, some of these measures may incidentally promote the presence of certain pests. Regular observation of the different insects in the system is thus essential.

6.2.9 INUNDATIVE BIOLOGICAL CONTROL

This method involves releasing a large amount of a specific antagonist to exterminate a particular pest. The antagonist is not expected to survive in the long term. A new release will be necessary in case of a new attack. This technique uses a biological agent as a highly specific pesticide, which does not kill beneficial insects.

6.2.10 CONVENTIONAL BIOLOGICAL CONTROL

This method involves the release of a specific antagonist to control a particular pest. The antagonist is expected to reduce the population of the pest without exterminating it, allowing it to survive in the long term.

These procedures (in 6.2.9 and 6.2.10) are difficult to implement in most African countries, as it is currently very difficult to obtain the necessary antagonists.

6.3 PLANT NUTRITION AND SOIL FERTILITY

Fertile soil improves crop health and resistance to pests and diseases. Sufficient fertilisation is therefore essential for the appropriate reaction of the plants to attacks. Over-fertilisation, especially with nitrogen, is not recommended. It will cause the plant to grow too fast and will not allow it to develop its protective mechanisms. A rich soil will also promote the presence of beneficial organisms as mentioned above.

6.4 HYGIENE

Infected or fallen fruit should be collected and directly composted, to limit pest reproduction. Sick plants are removed and burned before the disease spreads. An inspection for signs of disease should be carried out once a week for the first 2 months of cultivation. If signs of virus infection appear later, the plant can be kept but must be properly marked to avoid using it as planting material for the next season.

6.5 SEEDS

Ideally, resistant varieties to pests and diseases are used. Hybrid seeds are not suitable, as the system must be self-sustaining and the farmer should be able to collect seeds for subsequent seasons. Tuber seed should be selected from large tubers without signs of rot, insect or nematode damage. Tubers should be stored in the shade and not on the ground. Yam tuber pieces and cassava cuttings can be treated with ash. 150 g of ash is mixed with 8 l of water in a bucket. The tubers and cuttings are then soaked for 10 minutes and then dried in the shade in a dry, ventilated place. Information on harvesting, storage and seed preparation can be found in ch. 9.

6.6 ANIMALS

Animals can be used for weed control. Simultaneous dispatch of ruminants and poultry allows overgrazing and weed reduction. Ducks, especially Indian runner ducks, can be sent into the fields at any time. They will feed on many insects and will cause very little damage to the crops. Ducks can be kept in an infected field to control a particular pest. Chickens scratch the ground and may cause too much damage to a crop, so they are not suitable for pest control. Cats can be used to control rodents and birds, both in the field and in storage areas.

6.7 CROP ASSOCIATIONS

Growing several plants on the same plot reduces the risk of disease and pest attacks for the following reasons:

- Discontinuity of resources (see ch. 6.1)
- Greater diversity of insects, more beneficials (see ch. 6.2)
- Some plants secrete molecules that attract beneficials. They can be combined with plants that are susceptible to attack and disease.
- Some plants attract pests and keep them away from the main crop (trap crop), e.g. pennisetum which deflects stem-borers in cereals (Khan et al., 1998a). The pennisetum will attract the pests to lay their eggs. The eggs cannot hatch on the pennisetum, it is a trap plant.
- Some plants secrete molecules that repel many different pests (chilli, ginger, onion, garlic, marigold, lemongrass).
- Some plants secrete molecules that repel a specific pest from a particular plant. For example, onion planted in association with carrot will repel the carrot fly Psila rosae (Uvah & Coaker, 1984). Another example is Desmodium planted with maize, which repels stem-borers and armyworms (Khan et al., 1998b).
- If a crop is destroyed by a pest, the associated crop can compensate for this loss.

Crop combinations provide other benefits not related to pest and disease control:

- Better soil cover
- Better use of space and soil resources
- Diversification of production. Harvesting at different times.
- Higher yields than a monoculture, if the production of the different associated plants is combined.

These points are discussed in ch. 7, where various examples of associations, including those mentioned above, are described in more detail.

6.8 CULTIVATION UNDER NET

Some crops produce delicate fruits, in which many pests may lay their eggs, making the fruit inedible (tomato, pepper, eggplant, strawberry). It may be necessary to grow these crops under protection. A simple mosquito net covering is sufficient, but a mobile greenhouse may be more practical. The greenhouse should not create shade or heat build-up. A roof to protect against rain can be considered to reduce the risk of fungal diseases. Cultivation under a net is effective if combined with other measures:

- Installation of insect traps
- Association with repellent plants
- Repellent treatment

A fixed greenhouse is not recommended as it limits the possibility of rotation.

6.9 ROTATIONS

The principle of rotation is a key practice in agro-ecology, as it is in any farming system that seeks to limit its use of pesticides. The principle consists of alternating crops on the same field from year to year. The advantages of this practice are:

- Pests or diseases that have infected one crop will not be able to infect the next crop, as it will no longer be a host plant. In the case of many pests, the means of reproduction (eggs, spores, etc.) do not survive several years and cannot initiate a new infection once the original crop is put back on the same plot.
- The same principle applies to weeds. Alternating crops prevents a weed that is particularly competitive with a particular crop from establishing itself permanently.
- The integration of biofumigant crops for the control of soil-borne diseases (ch. 6.10).
- Crop rotation is essential to maintain soil fertility. It allows the alternation of demanding crops with undemanding ones, destructive crops with regenerative ones. It allows the integration of legumes and green manures (see ch. 4.3). It allows the alternation of crops requiring different nutrients, thus avoiding the depletion of a certain nutrient.

Rotation is probably the most effective means of controlling diseases and pests available on an organic farm.

For the reasons mentioned above, it is essential not to sow the same crop from year to year. Depending on the species, a longer or shorter break is necessary. It is also necessary to take a break between crops of the same family. Within a family, it is advisable to start with the most demanding and sensitive crop. It is sometimes difficult to plan a rotation including crop association. The diversity of crops from different families in the same field makes it difficult to find crops from other families for the subsequent seasons. The rotation must therefore be carefully planned. To plan an effective rotation, the following recommendations should be followed:

- Alternate the different families and species, respecting the necessary breaks and maximum percentages (see below).
- Cultivate species within the same family in decreasing order of requirement and sensitivity to diseases and pests.
- Alternate demanding crops with less demanding ones
- Alternate soil-destroying crops with regenerative ones.
- Alternate crops with high requirements for different nutrients.
- Alternate crops according to their morphology: upright vs. creeping, underground (tuber, root, etc.) vs. leaves (lettuce, amaranth) vs. fruits (vegetables, cereals, legumes).
- Always cover the soil. If no crop is planned, sow a green manure. In the dry season, plant a green manure or mulch, or leave the crop after harvesting the seeds.
- Plan a green manure crop at least every 4 years.
- Plan biofumigation every 4 years.

The different crop families, with the characteristics necessary for a well thought-out rotation, are presented here.

6.9.1 GRASSES (CEREALS, POACEAE)

Grasses, with the exception of fodder crops such as brachiaria and eleusine, are relatively demanding, especially in terms of nitrogen (N) and phosphorus (P).

Grasses have a deep and powerful root system, which allows them to recycle nutrients from deeper layers. They produce a large amount of biomass and can therefore enrich the soil with organic matter if properly managed.

Table: Main crops of the grass family. Crops are listed in decreasing order of nutrient need and sensitivity to diseases. The maximum column indicates the maximum proportion of the crop in the rotation. The column break x/y indicates the number of years x of break needed in a rotation of y years. For example, 2/3 means that out of 3 years, the crop should not be grown for 2 years.

Crop	Maximum [%]	Break [x/y]
Cereals (without fodder crops)	50	1/2
Grasses (including fodder crops)	75	1/4
Rice	33	2/3
Wheat	50	1/2
Maize	40	3/5
Sorgo	25	3/4
Pennisetum	40	3/5
Fonio/Mil	25	3/4
Brachiaria	40	3/5
Eleusine	25	3/4

6.9.2 LEGUMES (FABACEAE)

Legumes, especially fodder one, have a low nutrient demand, except for P. This is due to their ability to fix nitrogen and mobilise phosphorus from the soil. They can be used to enrich the soil with nitrogen (see ch. 4.3).

Table: Main crops of the legume family. Crops are listed in decreasing order of nutrient need and sensitivity to diseases.

Crop	Maximum [%]	Break [x/y]
Legumes (without fodder crops)	50	1/2
Legumes (including fodder crops)	75	1/4
Soybean	25	3/4
Pea	15	6/7
Cowpea	25	3/4
Groundnut	25	3/4
Greenbean	25	3/4
Mucuna	25	3/4
Desmodium, pigeon pea	50	1/2
Stylosanthes	50	1/2

6.9.3 TUBER AND ROOT CROPS

Underground crops (yam, cassava, sweet potato, potato, carrot, beetroot, onion, macabo, taro) require a lot of soil disturbance: at planting (ridges, mounds) and especially at harvest. Moreover, with the exception of sweet potato, these species grow very slowly and have little vegetation cover. The risks of erosion, leaching and loss of organic matter through decomposition due to air exposure are therefore very high. It is essential to alternate tuber and root crops with regenerative crops (green manures). It is not advisable to grow these species for more than 1 year in a 4 year period (except sweet potato). If soil protection measures are taken (mulching, agroforestry, intercropping), they can be grown every second year. Underground crops belong to different families, the recommended breaks for these families must therefore be respected.

6.9.4 6.3.3 VEGETABLES

Table (next page): Main vegetables, their families and necessary rotation information. Crops are listed in decreasing order of nutrient need and sensitivity to diseases. The necessary duration of the break is indicated over a period of 7 years. In case a family/species is grown 2 years in a row, a break of 2 years must follow. The break time must be respected between crops of the same family and between 2 identical crops. The nutrient column indicates the nutrient requirement of the crop. The product column indicates the type of vegetable.

Family	Specie	Maximum [%]	Break [year]	Nutriments	Products
Apiaceae	Carrot, Parsley, Celery	50	4/7		Leave, Root
Asteraceae	Lettuce, Sunflower	50	4/7		Leave
Brassicaceae	Cabbage, Raddish, Cauliflower	50	4/7	NK	Leave, Root
Cucurbitaceae	Pumpkin, Squash, Cucumber, Watermelon	30	5/7	NK	Fruit
Alliaceae	Garlic, Onion, Leak	30	5/7		Bulb, Leave
Malvaceae	Bissap, Okra	50	4/7		
Solanaceae	Tomato	30	5/7	NK	Fruit
	Potato	25	5/7	NK	Tuber
	Eggplant, Pepper, Chili	50	4/7	NK	Fruit

Be careful, sweet potato, even if it is not a solanaceae, is very close to this family. It is not recommended to grow solanaceae after sweet potato.

6.10 BIOFUMIGATION

Biofumigation is the use of toxic substances secreted by the roots of a plant to kill soil-borne diseases and nematodes. Most plants in the Brassicaceae family (cabbages, radishes, turnips, rape, mustard) have this specificity. Integrating these crops in crop associations and rotations helps to reduce soil-borne diseases and nematodes. For a better efficiency, it is advised to cultivate in the rotation a monoculture of brassicas. Mustard is very effective. The flowers contain substances that kill nematodes. The plant is sown, then after about 2 months the plant is cut and the flowers are incorporated directly into the soil (maximum 5 minutes after being cut). When buried, the plant produces gases that are toxic to nematodes and other pests. Alternatively, this can be done with turnips.

Crotalaria is a legume, but also has the potential to suppress soil-borne diseases. It should be mown and incorporated before flowering. The effect is short term, so crotalaria should be grown just before risk crops (vegetables, yams, cowpeas).

6.11 NATURAL TREATMENTS

In case of pest or disease attacks, some natural treatments produced with the resources of the system are possible. Care must be taken, as some natural products can be very toxic. For this reason, products based on tobacco are not recommended. The proposed treatments are repellents rather than pesticides. They should be applied directly to the plants to keep the pests away from them. Pests are unlikely to be killed by the product, but beneficials will also survive, compared to a pesticide application.

In case of pest attacks, treat with natural macerations once a week. Use one treatment 3 times, then change treatment. Treatments can be combined for greater effectiveness. If the treatment is not effective, try another treatment directly. In case of rain, apply again.

GARLIC MACERATION

Crush garlic cloves. Mix 2 tablespoons of garlic powder with 10 litres of water. Leave to soak for 12 hours. Mix 1 l of garlic mixture with 2 l of soapy water (3 caps of soap + 4 litres of water). Spray 1 litre on 10 m^2 of crop. Effective against aphids, mites and flies.

CHILLI MACERATION

Similar to garlic using ground chilli. Effective against sucking and biting insects, caterpillars, crickets and locusts.

COCKTAIL

1 kg of each ingredient: garlic, ginger, chilli, neem leaves, crushed, to macerate in 20 l of water. After one week, spray 1 litre of the product in 15 litres of water. Effective against many insects.

TOMATO MACERATION

Grind and macerate 200 g of leaves in 1 l of water for 12 hours. Filter and add 1 ml of soap. Spray 3 l per m^2. Effective against insects and fungal diseases.

PAPAYA MACERATION

Crush 1 kg of papaya leaves and mix with 10 l of water. Add a little clay, close the container leaving an air gap. Leave to ferment for 15 days and then filter. Spray 1 l per 10 m^2. Effective against fungal diseases (powdery mildew and rust).

MARYGOLD MACERATION

Macerate the flowers and leaves of marygold. Mainly for use against whitefly, noctuid moths and leafhoppers.

MACERATION OF NEEM LEAVES

3 kg of crushed neem leaves + 10 l of water + 30 g of soap, macerate for 24 hours. This is a general pest repellent. The residue of the leaves is applied to the feet of the crops as a fertiliser and nematicide.

NEEM OIL

Grind 2.5 kg of neem seeds. Leave to macerate for 12 hours in 10 litres of water, then filter. Mix with 5 litres of soapy water and spray. Use when all treatments against a pest fail. Use with caution and on wet plants (risk of burning).

NEEM POWDER

Grind neem bark and seeds, mix with water and leave to infuse for 1 day. Add soap and apply 2 litres per tree or per m^2. Use against soil-borne pests such as termites, especially to protect young tree shoots and sometimes crops.

MILK

Use to treat powdery mildew on vegetables. Mix 50 % milk and 50 % water to treat infected plants, 20 % milk and 80 % water to treat surrounding plants as a preventive measure.

INSECT TRAP

In the event of a pest outbreak, insect traps are set around infected crops. These can be either PET bottles or sticky traps with crushed papaya or banana. This treatment is most effective inside a net greenhouse.

7. CROP ASSOCIATIONS

This chapter describes the possibilities of crop associations in tropical Africa, including vegetable, cereal, tuber and perennial crops. Agroforestry is likewise presented in this chapter.

7.1 GENERAL

Crop association provides many advantages:

- Discontinuity of resources (see ch. 6.7)
- Biodiversity: attraction of beneficials (ch. 6.7), pollinators and beneficial organisms
- Repellent or trap effects of certain plants (ch. 6.7)
- Better soil cover: a fast growing crop (haricot) is grown in association with a slow crop (maize, yam) and will cover the soil until the slower one catches up. A creeping crop can also be grown with an erected crop, optimising soil cover.
- Better use of space: combination of erected, creeping and climbing plants. Use of live stakes (maize, trees) for climbing crops (beans, yams).
- Better use of soil resources. A P-demanding plant is planted in association with a N-demanding plant. A plant with a deep root system is associated with a shallow root system plant.
- Diversification of production. Harvesting at different times. Alternative yield in case of failure of one of the crops.
- Higher yield than a monoculture, if the yield of the different associated plants is summed. The yield of a single crop is generally lower than in a monoculture, because the planting density is lower to make room for the associated plants.

These advantages are summarised as a complementarity of the associated species, as well as by the facilitation of one species over the other (Hinsinger et al., 2011). Complementarity is defined as the reduction of competition between species through different resource use. Facilitation means that one species promotes the growth and survival of the other, either through direct positive mechanisms: alteration of light, soil moisture, soil nutrients, etc.; or through indirect mechanisms: beneficial changes in soil microbiology or chemistry. These interactions are most effective in extensive systems, where plants are limited and therefore benefit from the help of others.

To assess the effectiveness of an association, the so-called Land Equivalent Ratio (LER) is measured. This is the relative area needed in a monoculture to produce the amount produced with the association. For example, an LER of 1.2 for a bean-corn association means that it takes 1.2 hectares of monoculture to produce the same quantity on 1 hectare in association. The LER is calculated as follows:

$$LER = \frac{\text{Yield Crop A}_{\text{associated}}}{\text{Yield Crop A}_{\text{monoculture}}} + \frac{\text{Yield Crop B}_{\text{associated}}}{\text{Yield Crop B}_{\text{monoculture}}} + \frac{\text{Yield Crop C}_{\text{associated}}}{\text{Yield Crop C}_{\text{monoculture}}}$$

For example, the yield of maize in combination with bean is 3 t/ha, the yield of bean is 1.5 t/ha. The yield of maize in monoculture is 5 t/ha, that of bean is 2 t/ha. The LER is:

$$LER = \frac{3\ t/ha}{5\ t/ha} + \frac{1{,}5\ t/ha}{2\ t/ha} = 1{,}35$$

To summarise, an LER of 1 means that there is no yield advantage of the crop association. A lower LER means that the monoculture is more productive than the association, while a higher LER means the opposite. However, the LER only assesses the yield and not the other benefits of intercropping!

This chapter describes some of the most effective crop associations in tropical agriculture.

7.2 CEREAL-LEGUME ASSOCIATIONS

Grasses and legumes complement each other in a remarkable way. Their complementarity is well known and this association has been practised for thousands of years in almost all regions of the world: wheat-pea and barley-pea in the Mediterranean area, maize-groundnut and maize-bean in South America, sorghum-groundbean in Sub-Saharan Africa. This association is also the main component of many natural ecosystems, mainly grasslands, whether in temperate, arid or tropical climates.

The reasons for this complementarity are the following:

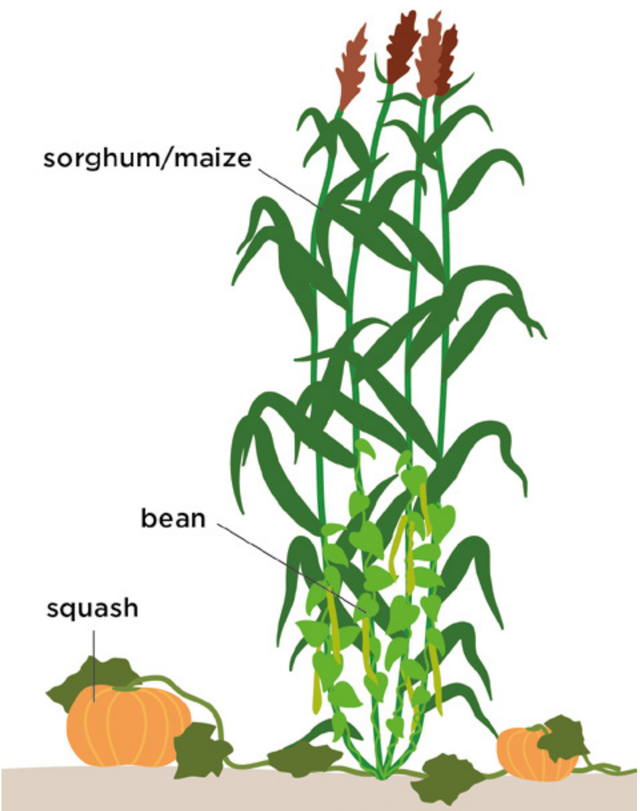
- Complementarity in space: erected grasses associated with bushy or creeping legumes.
- Complementarity of root systems: powerful, deep for grasses, shallow for legumes.
- Complementarity in nitrogen use. Grasses have a better nitrogen uptake efficiency, which reduces the nitrogen available to the legume. This will therefore promote biological nitrogen fixation of the legume.
- Complementarity in phosphorus use. Legumes are able to secrete large amounts of protons, carboxylases and phosphatases (Hinsinger et al., 2011). These molecules dissolve phosphate molecules attached to organic matter or in mineral soil particles, and make them available to both crops.

Possible cereal-legume associations

Cereal	Density [cm x cm]	Legume	Density [cm x cm]
Maize	100 x 40	Soybean	100 x 5
	80 x 40	Groundnut	80 x 30
	100 x 40	Cowpea	100 x 25
	100 x 40	Green Bean	100 x 20
Sorgo	80 x 20	Groundnut/Groundbean	80 x 30
	100 x 20	Cowpea	100 x 25
	100 x 20	Green Bean	100 x 20
Wheat	50 x 3	Chickpea	50 x 10
Barley	25 x 30	Pea	25 x 3

7.2.1 THE THREE SISTERS: BEAN, MAIZE, SQUASH

Association of sorghum/maize, bean and squash



The so-called three sisters association, or milpa, is a traditional association of the Maya in Central America. It combines maize, climbing beans and squash. The advantages are even greater than the simple grain-legume combination. The climbing bean can use the maize as a live stake. This allows the maize to be grown at the same density as the monoculture, while producing extra beans. The addition of squash, which can be replaced by another creeping cucurbit (melon, watermelon), allows the soil to be covered. There is a high degree of complementarity in space between erected maize, climbing beans and creeping squash. Maize can be replaced by a cereal such as sorghum.

Timing:

- Prepare the squash seedlings 3 weeks before the planned sowing.
- Sow the maize and transplant the squash.
- Sow climbing beans 1 week later.

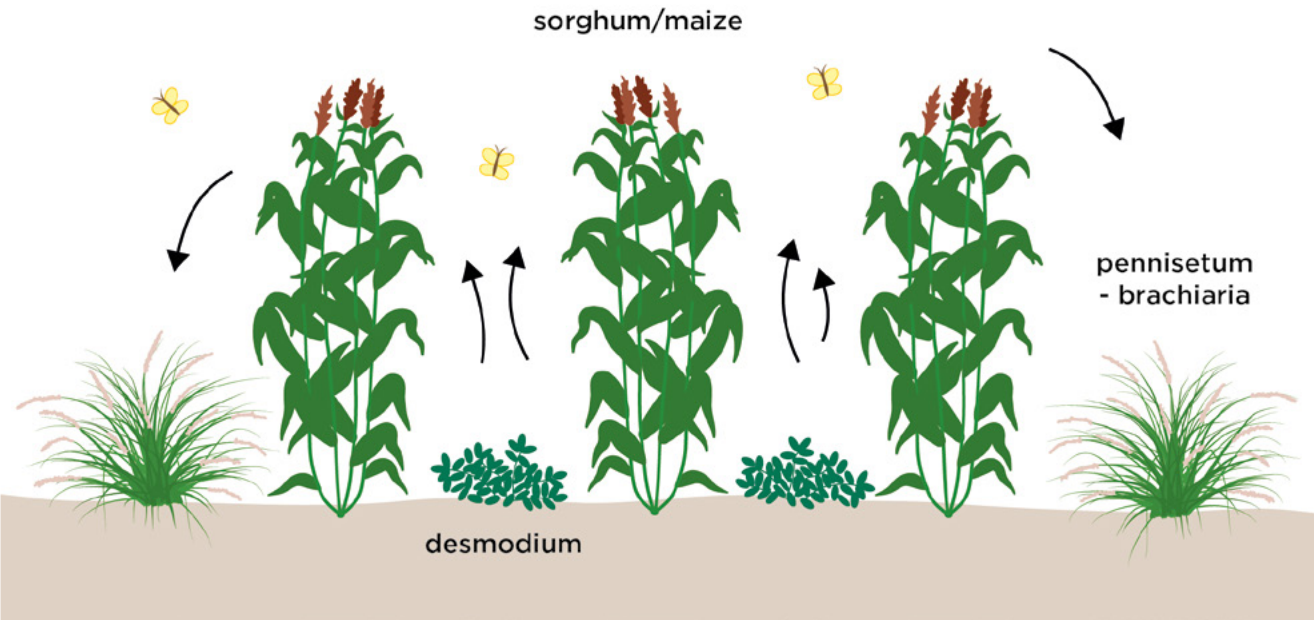
Spacing:

- Maize: 75 cm x 40 cm
- Climbing bean: 75 cm x 20 cm
- Squash: 75 x 250 (locally replaces one bean)

7.2.2 PUSH-PULL FOR PEST AND STRIGA CONTROL IN CEREALS

The push-pull technique consists of driving the pests out of the field by combining repellent plants with the crop (push) and attracting them out of the field with attractive plants (pull). The control of stem-borers and armyworms in cereals (maize, sorghum, millet, fonio) can be achieved with this system. An associated desmodium repels the pests, and a row of pennisetum planted around the field attracts and traps them. Desmodium is a quality forage legume, Pennisetum a quality forage grass. The intrinsic advantages of these plant families were discussed in the previous chapter. Brachiaria can be used instead of pennisetum. Its drought resistance makes it more suitable for a push-pull system in arid environment. Desmodium also has the advantage of causing suicide germination of witchweed (*Striga asiatica*) seeds. It can therefore control the damage of this parasitic weed and even clean the soil of its seeds.

Push-pull system with sorghum/maize, desmodium and pennisetum



Timing, installation, density and management:

- Plant pennisetum cuttings at least 2 weeks before the planned sowing date. Plant 1 to 2 rows depending on the size of the field (2 rows for a field of > 1 hectare). The planting distance is 75 cm x 75 cm. Pennisetum is planted with 3-nodded cuttings, 2 nodules to be buried at a 45° angle. The cuttings should be from the base of the stems of moderately mature plants.
- Sow maize in rows (75 cm x 40 cm). Leave 1 m between the last row of pennisetum and the first row of maize.
- Sow Desmodium between the rows of maize. Open a slot 2-3 cm deep. Mix 500 g of seed with 1 kg of sand and broadcast into the slot.
- Desmodium and pennisetum can be harvested as fodder for the first time after three months. One cut per month is possible thereafter. It can also be used as mulch or composted.
- After harvesting the maize, it is possible to either carry out a second maize cycle or to let the desmodium cover the plot as fodder/green manure.
- Pennisetum is difficult to eradicate. It is therefore advisable to leave it as a hedge between the plots.
- The same system is possible with sorgo or small millet.

7.2.3 RAINFED RICE AND STYLOSANTHES

The rice-stylosanthes association allows rainfed rice to be grown on infertile soils. It is suitable for regenerating degraded soil while producing rice. Indeed, the important nitrogen fixation and biomass production of stylo allows the creation of the manure necessary to fertilise the rice and enrich the soil. Stylo will also limit erosion and protect the soil. Finally, this association is ideal for soil cover and fodder production in the dry season. Stylo has the advantage of staying green in the dry season, and if not overgrazed, can cover the soil and produce fodder all year round.

Rice spacing:
Double rows 40 cm apart, 20 cm x 20 cm
(3-5 seeds per seedhole)

Stylosanthes spacing:
60 cm x 30 cm (7-12 seeds per seedhole)

Mow the stylo regularly to make room for the rice. Feed it fresh to the livestock. After the rice harvest, let the stylosanthes spread freely over the whole plot, mow regularly (every 2 months) to feed the livestock, do not mow lower than 20 cm as this may injure the plant. One month before sowing the next crop, the entire stylosanthes can be mown with a machete, unrolling the cover like a carpet.

7.2.4 FODDER

For sowing meadows, or for sowing green manure in a rotation, it is advantageous to combine leguminous and grassy forage species. In general, it is advisable to sow 50-70 % grass and 30-50 % legumes (see ch. 8.1) (Mosimann, Lehmann, & Rosenberg, 2000).

7.3 VEGETABLE ASOCIATIONS

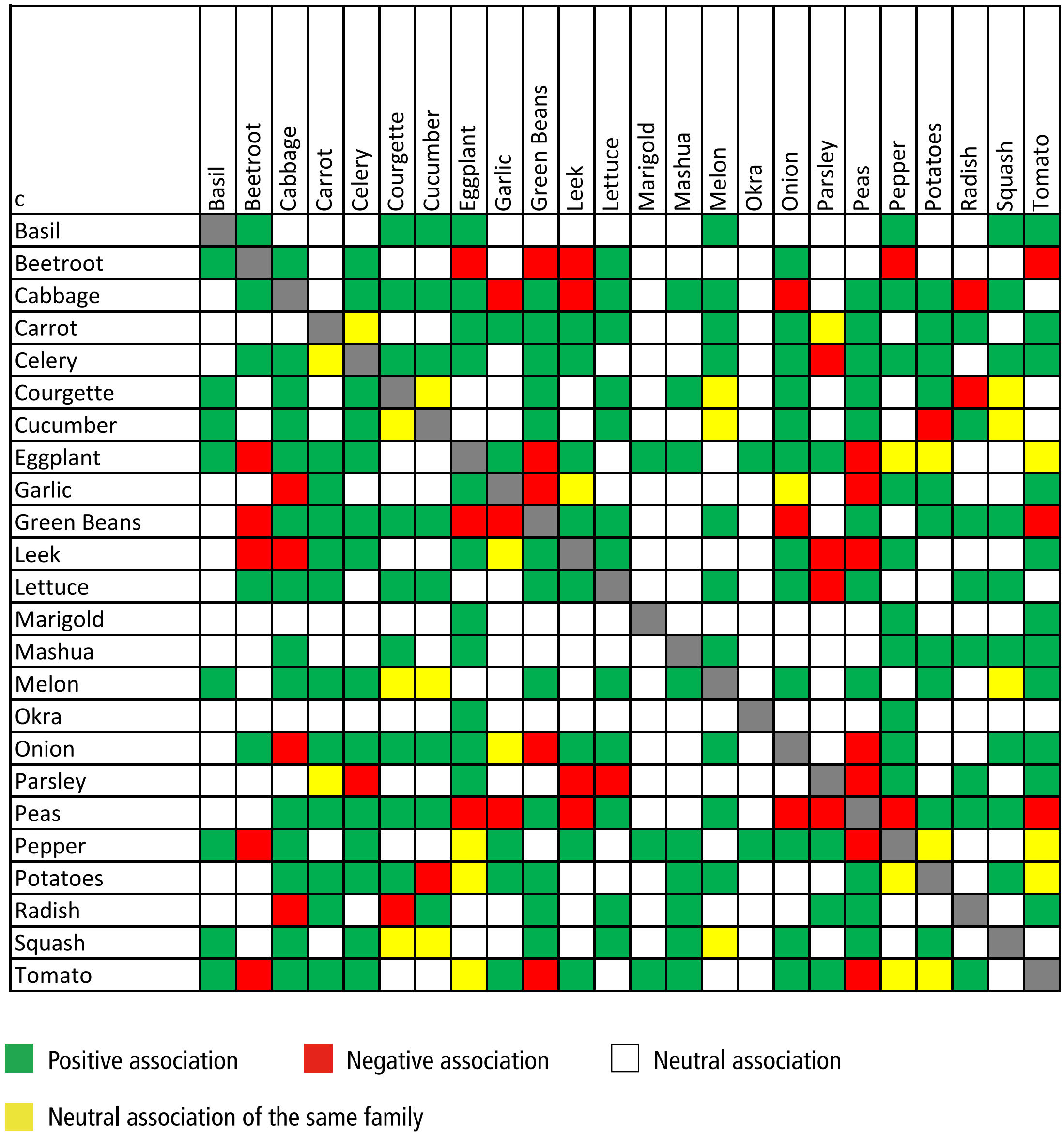
The species listed below secrete odours that repel many pests. They are generally not specific to a certain insect. It is advisable to include these repellent crops in vegetable associations.

- Onions, garlic and other alliums: Their smell repels many insects. Their small size and slow growth make them difficult to combine with large plants such as Solanaceae. They are therefore ideal for association with other small, uncompetitive crops, such as carrots, celery or beetroot.
- Ginger, turmeric.
- Mint.
- Lemongrass: Very strong repellent against many insects.
- Marygold, nasturtium: These flowers have a repulsive effect on white flies, moths and leafhopper. They can be combined with solanaceous plants to protect them from pests. This combination is usually not sufficient to control pests and additional measures must be taken: greenhouse cultivation and insect traps.
- Aromatic herbs (Lamiaceae): basil, thyme, oregano, savory.

Although they are not strict rules but more guidelines, the following general observations can help in planning vegetable associations:

- Alliaceae (garlic, onion) protect Apiaceae (carrot, celery).
- Alliums have a negative impact on legumes.
- Brassicas have a negative impact on Rosaceae (strawberry).
- Marygold and nasturtiums protect Solanaceae and Brassicas.
- Herbs (Lamiaceae) protect almost all vegetables.
- Combinations within the same family are rarely favourable.

Vegetable Association Table



7.4 TUBER AND ROOT CROPS ASSOCIATION

7.4.1 CASSAVA ASSOCIATIONS

Cassava is a very slow growing crop (10-14 months until first harvest). During the first months of cultivation, the soil is bare and intensive erosion and mineralisation of organic matter can occur. To cover the soil during this period and harvest a second crop before the main harvest, different crops can be planted in association with cassava (density: 1 m x 1 m).

- Pepper or chilli (1 m x 0.30 m): Growing pepper between cassava rows allows for an additional crop without limiting cassava yield (Olasantan, Salau, & Onuh, 2007). The seedlings (2-3 weeks old) are transplanted at the same time as the cassava cuttings and protect the soil.
- Legumes: Growing legumes in association with cassava provides good and rapid soil cover, nitrogen fertilisation and additional protein production. Two rows of green beans or groundnuts (33 cm x 20 cm) can be sown between cassava rows without reducing yield (Pypers, Sanginga, Kasereka, Walangululu, & Vanlauwe, 2011). Cassava spacing can be

reduced to 2 m x 0.5 m, which allows two cycles of legumes during the cassava crop, with the yield still not impacted. During the first cycle, 4 rows of groundnuts or beans are grown between the cassava rows (40 cm x 20 cm), followed by 2 rows during the second cycle (33 cm x 20 cm). Combining with soybeans or cowpeas may reduce cassava yields because they are too competitive.

- Stylosanthes: This legume provides excellent soil cover and fodder production. It must be regularly pruned to avoid too much competition with cassava. Two lines of stylosanthes are planted (30 cm x 30 cm) between the cassava lines.
- Agroforestry (AGF): Cassava is a crop that can be grown under semi-AGF or AGF (see ch. 7.4-7.5).

7.4.2 YAM ASSOCIATED WITH SQUASH

Yam, like cassava, is a slow growing crop with little soil cover (mainly at the beginning of the crop), which requires a lot of soil turnover. An input of organic matter and a rotation with a cereal may not be sufficient to prevent organic matter loss (Schneider, 2018). The association with a creeping crop covering the soil, such as squash or some other cucurbits, can therefore limit erosion and mineralisation of organic matter. Olasantan (2007) observed a 52 % decrease in weeds, a decrease in soil temperature, an increase in soil moisture and the presence of earthworms by combining these two crops. Yields of yam were even higher than in monoculture, despite the competition of squash.

Yam-Squash Association in Cameroun

Yam is grown on 0.50 m mounds at a density of 1 m x 1 m. Squash is grown between the mounds at a density of 1 m x 1 m. Squash can be replaced by another cucurbit: melon, watermelon, cucumber. Yam is also a suitable crop for AGF or semi-AGF (see ch. 7.4-7.5).

7.4.3 POTATO, ONION AND CARROT

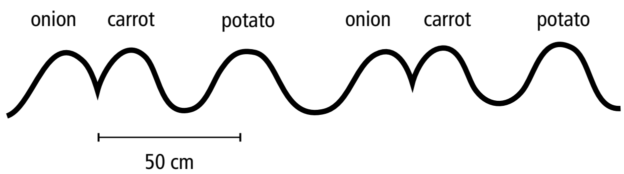
The onion has a repellent effect that protects the carrot and the potato. The carrot has a repellent effect that protects the onion. Onion ridges also allow for resource discontinuity, which limits the spread of fungal diseases.

Ridge spacing: 50 cm

Onion-carrot spacing: 20 cm

Row spacing:
Potato: 30 cm, Carrot: 3 cm, Onion: 10 cm

Carrot-Onion association in Mali



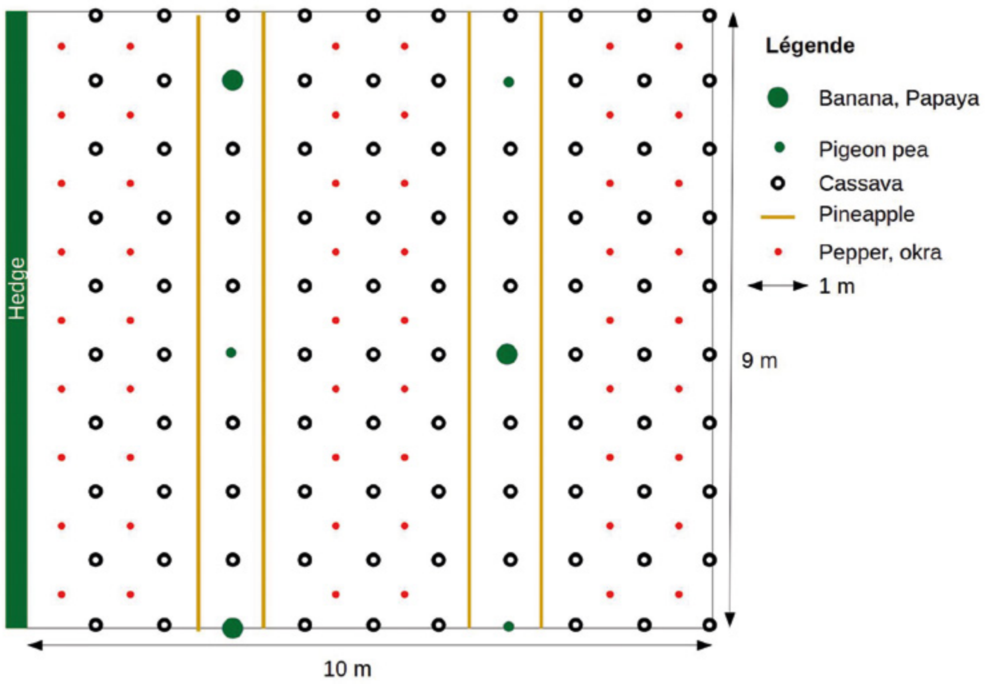
7.5 SEMI-AGROFORESTRY

Semi-agroforestry consists of combining annual crops with perennial crops. Unlike agroforestry, it is a temporary and not a permanent forest system. The perennials chosen are fast-growing, so that in less than a year they fulfil their role as trees: shade, protection against rain and rooting. These perennials are often short-lived: after a few years (2-5 years) they are removed and the system can be converted to a crop rotation of annuals only.

This type of system is ideal for growing tubers and roots: yams, cassava, taro etc. The perennial crops protect the soil and limit the danger of erosion and mineralisation caused by these crops. The shade is only partial, unlike in agroforestry, and therefore allows for good growth of annuals as well. Finally, the perennials are used to support climbing plants (yam, bean or others). The advantages of semi-agroforestry are:

- Optimal use of space.
- Good soil cover and high erosion control. Multi-layered cultivation allows interception of raindrops.
- Protects crops from wind and weather.
- Provides numerous refuges for beneficials.
- Limits evaporation.
- High productivity of annuals as shade is only partial. However, choose crops that appreciate or endure shade: yam, taro, sweet potato, strawberry and berries.
- Easy to manage. Annual recultivation is very quick, as is installation.
- Perennial crops that can be used in semi-agroforestry are
- Fruits: Papaya, banana, plantain, pineapple.
- Forages: Pigeon pea, moringa or other fast growing legume shrub.

An adequate planting distance for perennial crops is 4 m x 4 m. The plan below shows a suggestion of a semi-agroforestry field with banana, papaya and pigeon pea planted at a spacing of 4 m x 4 m. In addition, rows of pineapples are planted perpendicular to the slope to limit erosion. The remaining spaces are occupied by annuals: this year cassava, pepper and okra.



The annuals associated with these perennials should be rotated as in a normal annual field. It is advisable to start with sun loving crops (maize) before the perennials create shade. An example of a rotation would be:

- Year 1: Maize then vegetables
- Year 2: Yam and squash
- Year 3: Cassava and pepper
- Year 4: Sweet potato

The photos above show a semi-agroforestry plot within an agroecological system.
The perennials are plantain, papaya and pigeon pea. This year, the annuals were yam and squash.

7.6 AGROFORESTRY

Agroforestry is the cultivation of trees for the production of wood or food, in association with annual crops or livestock. A multitude of agroforestry design exist, depending on the needs of the farmers and the constraints of the environment. The advantages of agroforestry are the following:

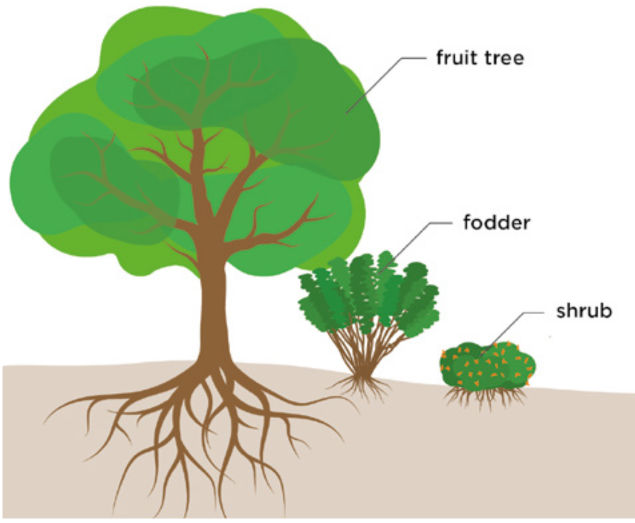
- Increases fertility and improves soil structure.
- Limits erosion.
- Promotes water infiltration.
- Conserves moisture in the plot.
- Produces wood.
- Allows the production of fodder, fruits, medicinal plants, honey and other products.
- Protects crops from wind.
- Provides refuge for beneficial insects.
- Positive interactions between associated crops.
- Optimal use of light and space.
- Low maintenance labour.

Unlike semi-agroforestry, this is a permanent system. It takes several years (4-10 years) until the system is installed. It is therefore not possible to integrate agroforestry plots into a rotation.

Agroforestry consists of combining various types of perennial crops, seeking complementarity between them. For example, one can combine:

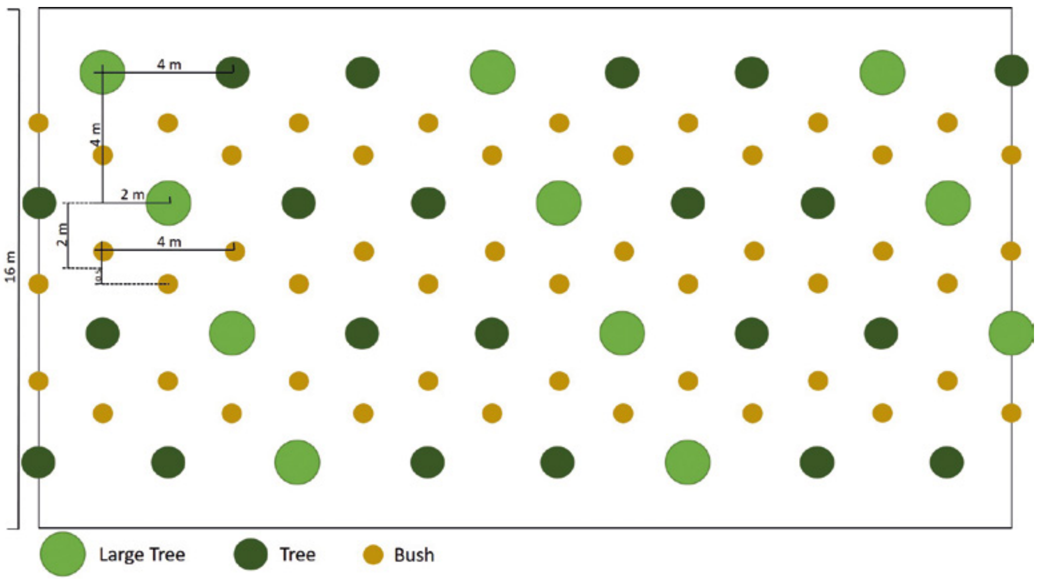
- Fruit trees with fodder trees and wood trees.
- Deep root systems with shallow root systems.
- Fast-growing trees during installation with slower-growing trees to take over.
- Trees of different sizes: strata system.

Association of trees of different sizes on 3 stratas



In addition to perennial crops, it is possible to associate annuals either during the establishment phase before the shade is too strong, or crops that appreciate the shade once the system is established. It is also possible to use the agroforestry plots as grazing areas. Fodder crops can be sown as ground cover once the trees are established: perennial groundnuts, desmodium and different grasses. Animals can then graze on the fodder trees and on the ground cover.

Example of an AGF system for a semi-aride climate.
Species are then chosen between fruit and fodder trees.



7.7 LIVE HEDGES

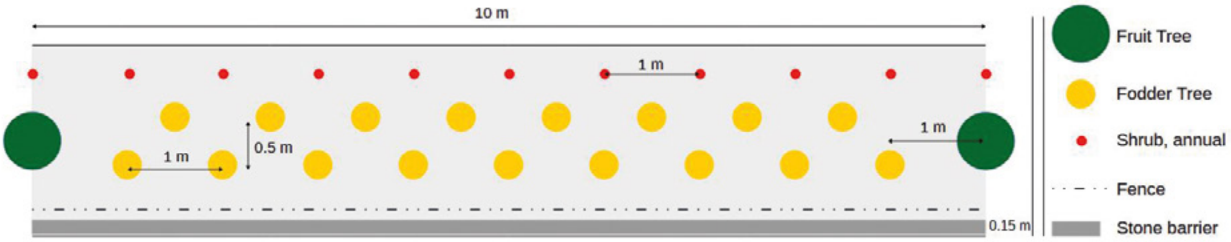
A possible agroforestry practice is to plant hedgerows around plots or farms. Hedges provide the following benefits:

- Protection of crops from wind, weather and pests.
- Refuge for beneficial insects: predators, beneficials and pollinators.
- Production of quality fodder.
- Natural barrier against wandering animal grazing.
- Reduction of erosion. To achieve this, they should be planted perpendicular to the slope.

They are ideally made up of fast-growing leguminous trees to allow for rapid establishment and to provide a nitrogen input into the system. Some fruit trees can be added. They can be designed in several layers (see ch. 7.5).

Young live hedge in Burkina Faso

Example of a 3 strata hedge



STRATUM 1: FRUIT TREES

Fruit tree seedlings are prepared in nurseries and transplanted when they are robust. Forage trees are pruned to allow the fruit trees to overhang the hedge and produce fruit.

Example: Mango, citrus, avocado, palm, guava

STRATUM 2: FODDER TREES

Fast-growing trees (several metres per year), with large foliage production. Most of these trees are leguminous and will contribute to the nitrogen enrichment of the system. Example: *Gliricida sepium, Sesbania sesban, Cajanus cajan, Leucaena leucocephalia, Calliandra, Acacia, Eucalyptus, néré, neem, moringa*.

STRATUM 3: SHRUBS AND ANNUALS

At the foot of the hedges, shade-loving crops that can be used to attract beneficial insects or repel pests are planted.

INSTALLATION OF THE LIVING HEDGE

- Protect the young shoots from animals with a barbed wire fence.
- Sow the fodder trees first.
- Weed regularly for the first few weeks and occasionally for the first year.
- Prune fodder trees to a height of 1.5-2 m, use the leaves as fodder. Prune hedges to the south of the plot lower to limit shade.
- Prune fodder trees to leave space for fruit trees, do not prune fruit trees.
- Plant shrubs at the foot of the trees when the hedge has reached a height of 1.5-2 m.

8. LIVESTOCK IN AGROECOLOGY

This chapter discusses the role of animals in an agroecological production system, focusing on their role in biomass recycling, manure production and pest management. Different agroecological practices for their nutrition and health are presented.

Animal husbandry is almost essential to the functioning of an agro-ecological production system. Animals allow the valorisation of biomass (hedges, green manure, crop biomass) into food products (eggs, milk, meat and others) and manure. They enable the recycling of many nutrients, rapidly transforming them into a plant available form. Animals allow the production of reactive nitrogen fertiliser from legume biomass, and thus provide an alternative to synthetic inputs. It thus allow the farm to operate in a closed loop (without external fertilizer).

Livestock farming in agroecology is mainly extensive. Its primary role is the valorisation of biomass and the production of manure. Agroecology is not adapted to intensive production, as animals are fed mainly with fodder that is not edible for humans: grass, kitchen waste, crop waste; or by hunting wild insects. The animals need to be sufficiently fed to produce quality manure.

8.1 RUMINANT NUTRITION

Ruminants (sheep, goats, cattle) have the capacity to digest roughage: grass, vegetable biomass, crop biomass, hay, etc. They can be fed with hedgerow biomass (moringa, leguminous trees and others), green manure biomass (stylosanthes, desmodium, brachiaria, eleusine, pennisetum), intercropping biomass (pennisetum, desmodium), crop biomass (sweet potato, bean/cowpea/soybean) and grazing.

Roughage can be provided in 3 different ways:

Cut and carry: The biomass is mown and fed fresh to the ruminants. This makes it possible to keep the animals in the barn while feeding, and thus to collect the dung more easily. This system is almost the only option for feeding with biomass from hedgerows and associated crops, as grazing would cause damage to the main crops. Cut and carry is very labour intensive. It is necessary to mix grass and legume biomasses to provide a balanced diet.

Hay: It consists of drying roughage, with the aim of preserving it to feed animals in the dry season. Young, nitrogen-rich biomass should be used: grasses, desmodium, eleusine, perennial groundnuts, young branches or leaves of leguminous trees. Stylosanthes or sweet potato biomass cannot be made into hay, animals would not eat it. Mow the biomass and leave it to dry for 2 to 3 days in the sun. This should be done during a dry period, as rain on the biomass will greatly reduce its quality (nutrient leaching, rotting). Hay can be harvested and stored as soon as it is completely dry. Stored wet hay will rot and lose its quality. In addition, hay decomposition due to moisture will generate a lot of heat and may start a fire. Hay should be stored in a dry place protected from rain.

Grazing: Grazing is the practice of letting ruminants feed themselves on meadows. This can be done on large areas of fallow land. However, overgrazing will denude the soil and expose it to erosion, while reducing biodiversity. Alternatively, grazing can be carried out on small well-cared meadows. The soil is first turned over and then a mixture of quality forage plants (grasses and legumes) is sown. Once the plants are well established, the area is divided into different parts (4-5) with fences. Animals start grazing on one of the plots. Once this plot has been grazed, but before the overgrazed plants die, the animals are sent to the next plot. This allows the fodder crops to constantly regrow and avoids selective grazing. If the animals have access to an area too large, they will not eat the less palatable species, and these will accumulate, making the quality of the meadow decrease. Animals should not be kept on a plot where the vegetation has not fully grown back. In this case, the animals should be left in the pen and fed with fodder for as long as necessary.

A protein supplement can be considered by feeding additional legume grains: mucuna, pigeon peas, legume grains from hedge trees. This can be done by feeding the biomass directly without removing the grains. Pure grains can also be fed, but these must be lightly cooked beforehand. Legume grains contain toxic substances and should not be eaten raw in large quantities.

It is essential that ruminant roughage is balanced between legumes (protein) and grasses (carbohydrates, fibre). Unbalanced forage will cause digestion and health problems to the animal. Forage that is too high in energy and too low in fibre (legume grains and corn kernels) can even cause the death of a ruminant by acidification of its stomachs. A balanced diet contains between 50 and 70 % grasses and 30 to 50 % legumes (Mosimann et al., 2000).

Ideally, ruminants receive 2 times a day a supply of roughage (morning and evening). The rest of the day they feed while grazing. An intake of protein (legume grains) can be made once a week.

8.2 POULTRY NUTRITION

The role of poultry in the agroecological system is to valorise kitchen and crop waste. They can eat peelings, dry bread, spoiled fruit, etc. Chickens can be kept on a plot after the harvest. They will eat the remains of unharvested crops (peanuts, cereals, vegetables), turn the soil, fertilise it and deworm it. The ducks can be sent into the crops at any time. They will eat the pests without damaging the crops. Ducks can be used in rice fields: they fertilise, aerate the soil (limit methane emissions) and control pests and weeds (Zhiqiang et al., 2008).

Poultry are sent to graze with ruminants. They will feed on insects as they hunt. Too many chickens should not be sent to the same paddock, as they may dig up and kill the fodder plants. Poultry nutrition is supplemented with cereal grains (maize, eleusina, sorghum) and legumes (pigeon peas, leguminous trees, cowpeas). Legume grains should be lightly cooked to limit their toxicity.

8.3 ANIMAL HEALTH

Sturdy animals adapted to the local climate should be used. To ensure the health of the animals, their shelter should be regularly cleaned and protected from wind and rain. Their diet should be sufficient and varied. Sick animals and tired, unhealthy females should be isolated to avoid contamination. Females are isolated during farrowing. It is advised to plan breeding so that females are pregnant during the season when food is abundant. To control breeding, goats that are not to be mounted can either be confined or the male can be completely separated.

Acacia (ideally A. raddiana, A. nilotica and A. karoo) and moringa leaves have shown potential to fight gastric parasites (helminths, nematodes) of goats and sheep (Kahiya, Mukaratirwa, & Thamsborg, 2003; Korsor, 2018). It is advisable to include these species in the diet of ruminants. Pawpaw seeds can be used to combat gastric diseases in poultry.

8.4 ANIMAL HUSBANDRY

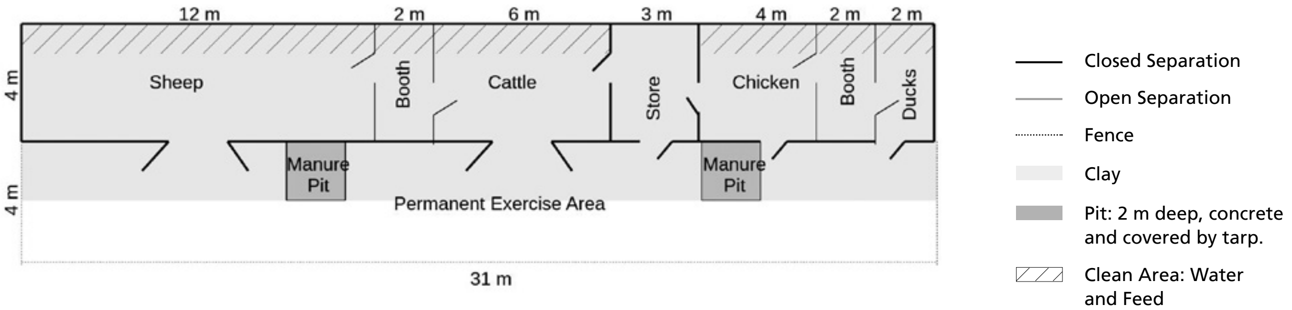
The animals should have a shelter that protects them from rain, wind and sun. The shelter should allow air to pass through so that the animals do not get too hot. There should be enough space for the animals so that they do not fight and to limit the transmission of disease. The following is a list of recommendations for good small-scale animal husbandry in a tropical climate

- A shelter is built of wood. The fronts are not filled in. They allow air and light to pass through and ensure good ventilation. The walls should not exceed the animals eyes.
- Goats and sheep can be kept in the same room. Cattle should be kept separately, as well as the different poultry: ducks, geese and chickens.
- Each room should contain an isolator to separate the respective livestock. The isolator should prevent physical contact between the sick animal and the others but should allow visual contact.
- Food and water are provided in feed and water troughs, where the animal cannot defecate.
- Straw (rice, maize, sorghum, other grasses) is used as bedding.
- Defecation is swept up daily and stored conveniently. Straw mus be changed regularly.
- Provide nests and perches for poultry, making it easier to collect eggs.
- Plant trees to provide shade for the animals when grazing. Animals can graze in agroforestry areas. Goats can climb on trees to graze.

The space required for each adult animal in a barn is as follows

- Cattle: 5 m^2/head
- Goat and sheep: 2 m^2/head
- Chicken or duck: 0.50 m^2/head

Example of a stable plan for 20 sheep, 4 oxen, 30 hens and 15 ducks.



9. SEED COLLECTION AND CONSERVATION

This chapter explains how to collect seeds of common crops grown in sub-Saharan Africa.

Seed recovery brings the following benefits to producers:

- Lower investment at the beginning of the season.
- Possibility to grow high value crops, where the cost of seed is difficult for producers to afford (vegetable crops). Propagation of seeds from one producer to another makes this possible.
- Autonomy from the seed market as well as from the financial situation of the producer. He does not risk being left without seed if he cannot afford to buy it.
- Preservation of genetic diversity and the possibility for the producer to select according to his own criteria.

However, the use of one's own seed is in conflict with the use of new seed selected for resistance to particular diseases. It is therefore advisable to buy external seed from time to time, especially if poor performance is observed among the varieties used. Hybrid varieties are generally not suitable for farmers' seed production. New generations of hybrid vegetables are often not fertile.

This document explains how to produce seeds for the following years. It explains the two ways of reproducing plants: vegetative reproduction and reproduction through seeds.

9.1 VEGETATIVE REPRODUCTION

Using vegetative reproduction means using certain parts of the plant (tuber, stem, cutting) to create a new plant. This has the advantage of simplicity, but has several disadvantages:

- The new plant is genetically identical to the mother plant, so there is no possibility of selection and diversity is low, which increases the risk of disease.
- Most diseases are transmitted to the new plant.
- The weight of the seeds is often very high and the shelf life is short, which is especially problematic for marketing.

In any case, some plants do not produce seeds, which makes the use of vegetative propagation necessary.

Since this method of propagation does not prevent disease transmission, it is essential to monitor crops in order to remove and burn diseased plants. Plants infected with a virus, such as cassava mosaic (picture opposite), can be kept but must be marked so that their means of reproduction are not used.

For vegetative reproduction, cuttings, suckers, tubers, corms or rhizomes are used.

Cassava leaf attacked by mosaic virus in Guinea.

9.1.1 PROPAGATION BY CUTTINGS AND SUCKERS

In general, live plants are needed from which cuttings are taken and planted directly in a new location. The shelf life is minimal (maximum a few months).

Cassava: Cuttings are cuts from the middle part of the youngest stems. The cuttings must be clean. Stems used as cuttings should be 2-4 cm thick, 30-40 cm long with 7-10 nodes. Stems are selected from plants showing no signs of virus infection and between 6 and 18 months old. They can be stored for up to 2 months in the shade at the foot of a tree, with the bottom of the stems in moist soil. When planting, the lower part of the cutting is cut off. The planted cutting should be between 20 and 30 cm long and have 5 to 8 nodes. Plant the cuttings horizontally (less than 10 cm deep), obliquely or vertically.

Forage grasses (Brachiaria, Pennisetum, Andropogon, Lemon grass): Cut stems of mature plants at 20 cm from the ground. The cut should be clean at an angle of about 45°. The stem can then be cut into several parts, each containing 3 nodes. The cutting is planted with two of the three nodes below the soil surface.

Pineapple: Suckers are used as a means of propagation, i.e. regrowth of the plant as shown opposite. Ideally, suckers from the underground or aerial base are used. The suckers must then be prunned, which consists of removing the leaves and roots so that the eyes are exposed. The suckers are then treated against insects and fungal diseases by soaking them in an ash mixture.

If the treatment is not effective, an insecticide-fungicide mixture is used the following season. The suckers are left to dry upright for 12 hours and then planted, but they should not be planted too deep.

Pruned pineapple suckers (right) and unpruned (left)

Pineapple shoots trimming.

Banana and plantain: Cut off suckers 0.8-1.20 m high from the foot of the mother banana plants. The cut must be straight (it is necessary to cut through the corm – a kind of underground tuber). Then simply transplant the shoot into a hole measuring 30 cm x 30 cm x 30 cm. Once the banana plant has produced fruit, the next suckers are collected. Since the mother banana tree will die, a sucker should be left at the site of the mother banana tree.

9.1.2 PROPAGATION BY TUBERS, RHIZOMES OR CORMS

Tubers, rhizomes and corms are underground organs in which the plant stores energy. They can therefore be used as seeds. Since signs of disease are not visible on the tubers, it is essential to separate the tubers from diseased plants and use them only for consumption. Seed tubers are then selected from large tubers without signs of rot, insect damage or nematodes.

It is then necessary to store the tubers until planting. The tubers should be stored in the shade, high up (no contact with the ground), and protected by a straw roof that allows rainwater to percolate (see photo).

Yams: Just before planting, the yam tubers are cut into 200 g pieces. The yam tuber pieces are then treated with ash or an ash-fungicide mixture. Soak for 10-15 minutes and then dry in ventilated shade.

Example of an appropriate yam storage.

Sweet potato: The whole tubers are placed in raised beds in the nursery. When the stems reach 20-30 cm in length and 7-8 leaves, they are harvested as cuttings. Two harvests of 8-9 cuttings per potato can be expected. It is also possible to take the stems directly from living plants.

Taro and macabo: Same as yam, but processing is not essential.

Ginger: The rhizomes are cut into 20 cm wide pieces with 3 eyes.

Potato: Potatoes should be stored in a cool, dark place. 20-30 g potatoes are planted when they start to sprout.

9.1.3 TREATMENT SOLUTIONS

Ash mixture: 150 g ash + 8 l water.

9.2 SEED PRODUCTION

In contrast to vegetative propagation, reproduction by seeding, or generative propagation, allows the mixing of plant genes to create new individuals. In addition to greater genetic diversity and lower susceptibility to disease, selection is possible. The best individuals from each generation can be chosen. Seeds can be stored for several years and the risk of deterioration of the material is lower than for vegetative means. Finally, only a small amount of seed is needed to sow a field, which facilitates transport, propagation and marketing.

9.2.1 GENERATIVE REPRODUCTION OF PLANTS

Seeds are the means of generative reproduction of plants. To create seeds, the female organs of the plant (pistil) must be fertilised by pollen, which is produced and released by the male organs (androecium). The pistil and androecium are found in flowers. A flower can either contain an androecium only (male flower), a pistil only (female flower) or both (hermaphrodite flower). Three types of plants are distinguished by their flower types:

- Monoecious plants: They have both male and female flowers on one plant.
- Dioecious plants: They have only flowers of the same sex on one plant.
- Hermaphroditic plants: They have hermaphroditic flowers.
- This is very important for seed production, as an unfertilised flower will not produce seeds. Understanding how different plants reproduce can provide the ideal conditions for seed creation.

There are different ways in which plants fertilise themselves, to bring pollen from a male flower to a female flower.

Cross-pollinated plants cannot fertilise themselves. They need a vector to carry the pollen from the flowers of one plant to another. This is done either by insects or by wind (very light pollen).

Self-pollinating plants can fertilise themselves. They often need wind, rain, insects or animals to shake them and make the pollen fall from one flower to another. Plants are never solely self-pollinating, there is always a transfer of pollen between plants.

9.2.2 CULTURAL MANAGEMENT OF SEED CROPS

A plant that is cultivated for the production of seeds is called a seed crop.

Growing time: For some crops, such as fruit vegetables (tomatoes, squash, aubergines, etc.), the seeds can be collected from the ripe fruit, so the cultivation time is very similar to that of a production crop. On the other hand, some species of leaf or root vegetables (lettuce, carrot) will take much longer to produce seeds than to produce the leaves or roots that is usually harvested.

Sun, nutrients and water: The cultivation of seed crops is often much more demanding than a production crop, as the plant needs more energy to produce quality seeds. It is therefore important not to grow seed crops in the shade. It is also important to ensure that fertilisation is sufficient, while avoiding too much nitrogen. Water supply should also be sufficient until flowering. With the exception of fruit vegetables, the water supply should then be drastically reduced to accelerate grain ripening. It is advisable to cover the seed crops after flowering to better control the water supply.

Protection: It is important to protect seed crops from rain. Rain can wash away light and small seeds (e.g. lettuce). It is therefore important to cover sensible crops after flowering (example below).

Spacing and staking: Seed crops can become very large and tall and take up a lot of space.

It is essential to double the planting distances of the production crop, and to build strong stakes. It is imperative that fruits and seeds do not touch the soil to avoid rotting (except for squash and cucurbits).

Harvesting: Depending on the species, seeds are taken at different stages of maturity and in different ways (see ch. 9.5).

9.2.3 PREPARATION OF HARVESTED SEEDS

Soaking (S): If the seeds do not well separated from the pulp (e.g. aubergine), soak for 12-24 hours in cold water.

Wet process without fermentation (W): This technique is used for most fruit vegetables. The seeds are extracted from the fruit and rinsed in a sieve with water until the flesh of the fruit has disappeared. The seeds are dried as quickly as possible in a well-ventilated place at a temperature of 23-30° C.

Wet process with fermentation (WF): This technique is used for tomatoes and cucumbers. The purpose of fermentation is to remove the film that surrounds the seed and prevents it from germinating. Use a spoon to scoop out the seeds and surrounding pulp and place in a glass with a little water. Cover the glasses loosely and set them at a temperature of 23-30° C. Stir the glasses regularly and observe: the good seeds become rough to the touch and sink to the bottom of the glass after about two days. If there is not enough fermentation, there is not enough pulp, add a pinch of sugar. Do not leave the seeds in the water for too long (max. 2 days), as they may germinate.

To rinse, add water to the fermented mixture and shake until the seeds fall to the bottom of the glass. Empty out the pulp and any dead seeds that float. Repeat the process until the water runs clear. Dry as quickly as possible (in a coffee filter or on a plate) in a ventilated area. The seeds should be dry within 2 days.

Dry process (D): For all seed crops that are not fruit vegetables. Drying should be sufficiently long (min. 1 week) and the temperature should not exceed 35° C to avoid damage. A dry and ventilated place is ideal. In grain legumes, cereals and many pepper and chilli varieties, the seeds dry relatively well while they are still inside the fruit. The seeds can therefore be left to dry on the plants. Beware that if it rains and the weather remains wet for a long time before harvesting, the seeds of some species may start to germinate. For other crops, such as Brassicas, Apiaceae and Asteraceae, it is common to pull out or cut off whole plants to allow the seeds to ripen and then dry under cover while they are still enclosed in their fruit.

Once the seeds are dry, it is necessary to thresh the plants to remove the seeds from the rest of the plant.

- For easily detached seeds (grasses, spinach), place the plant in a bag (jute, plastic) and tap it against a wall or the ground.
- For easy-to-remove but damaging seeds (legumes, lettuce, cabbage), beat the bag against a soft surface or walk on it barefoot.
- For hard-to-remove seeds (carrots, radishes), tap the bag with a stick.

The result contains the seeds and a lot of plant waste. These must therefore be removed manually and/or by lifting the bag and/or with the wind.

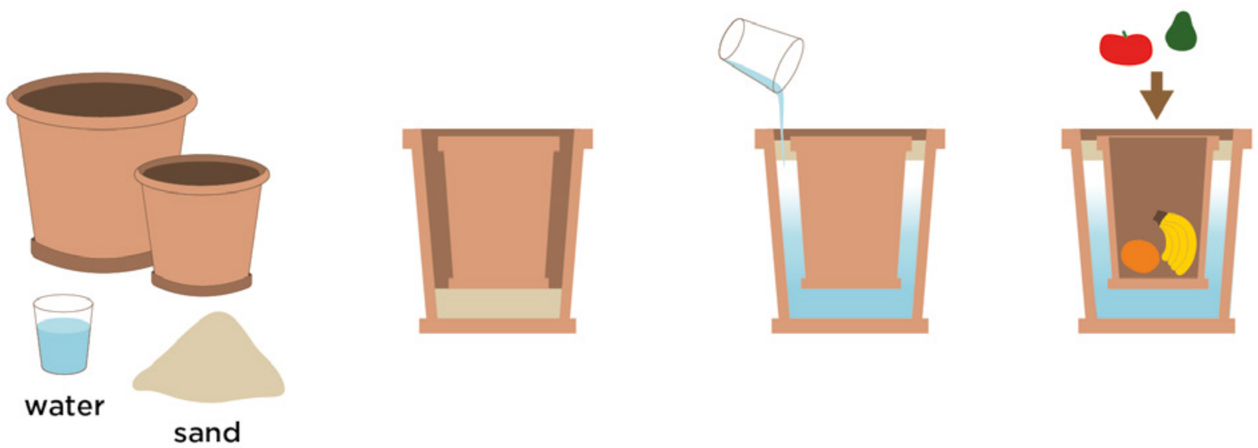
9.3 SELECTION

Take seeds from the most productive and, above all, the healthiest plants. Never take seeds from a sick plant, and of course no infected seeds directly. More advanced selection requires much more work and knowledge and is not covered in this document.

9.4 CONSERVATION

The seeds must be perfectly dry to be preserved. They are stored in small bags in glass jars. The jar protects them from rodents, pests and contact with air, which causes deterioration of the seeds. Name the jars (date, variety). The jars are stored in a cool, dark and dry room. Ideally, the temperature should be between 0° and 10°. For this purpose, place the vegetable seeds in "desert fridges" (scheme below).

Construction of a desert fridge with 2 terracotta pots, sand and water.
It can be used to store vegetables or seeds. The temperature is 10° lower than outside.



Seeds are divided into 4 categories according to their shelf life:

- 1: very sensitive (a few months)
- 2: short life (2-3 years)
- 3: medium life (4-5 years)
- 4: long life (> 5 years)

Before using the seeds, it is advisable to do a germination test. The germination test is mandatory for old seeds as well as for seeds harvested under bad conditions. Place between 50 and 100 seeds in wet paper. Roll them into a ball and place it in a plastic bag with a hole in it. Wait for 2-3 weeks (4 for Apiaceae) and then calculate the germination rate. Adapt the quantity of seedlings according to this rate.

9.5 CROP SPECIFICITIES

In this chapter, the characteristics of the different crops are described from a seed production perspective.

9.5.1 FRUIT VEGETABLE-SOLANACEAS

Reproduction: Self-pollinated, hermaphrodite

Number of seed crops required: 6-12

Staking: Yes

- Harvest the fruit when it is fully ripe (as for consumption). The fruit changes colour as it ripens.
- Do not use rotten fruit for seed collection. Use large, healthy fruits of the desired shape.
- Use only seeds from the first 3-5 fruits of each plant. For tomatoes, use the fruit from the first two bunches.

Specie		Treatment (ch. 9.2)	Shelf life (ch. 9.4)	Grains per fruit
Lycopersicum esculentum	Tomato	HF	4	90-150
Capsicum annuum, chinense, frutescens	Peppers	H	3	150-250
Capsicum annuum, chinense, frutescens	Chili	H	3	50-150
Solanum melongena, ethiopicum, macrocarpon, torvum	Eggplant	TH	4	50-100

9.5.2 FRUIT VEGETABLE – MALVACEAS

Reproduction: Self-pollinated

Number of seed crops required: 6-12

Shelf life: 2

Number of seeds per fruit: 40-80

Okra: The fruit is harvested riper than for consumption. Wait until the fruit is brown and dry, then harvest 3-4 fruits per plant. The fruit is opened by hand and the seeds are dried.

Bissap: Harvest the fruit when it turns brown, before it is fully ripe, otherwise the seeds will fall out. Dry the whole thing and then clean it by the dry method.

9.5.3 FRUIT VEGETABLES – CUCURBITS

Reproduction: Cross-pollinated (insects), monoecious

Number of seed crops required: 6-12

Number of seeds per fruit: 100-300

Shelf life: 3

- Be careful not to grow several varieties of the same species in the same year as they will crossbreed. This is difficult, as there are many varieties of squash that belong to a few species, including zucchinis and egusis.
- Only 2-4 fruits of the desired shape are allowed to mature per plant. The other fruits are removed quickly and eaten.

- Cucurbit fruits should be harvested when they are fully mature, which for some species means later than the ripening of food crop. Fruits are mature when the stem becomes golden-brown, dried out and sometimes detaches from the fruit. Additional signs are a skin that can no longer be scratched with the finger and/or a hollow sound when the fruit is knocked.
- The ripe fruit is harvested and stored in a cool, aerated and dry place (as for yam storage, see above) for 3 to 8 weeks.
- Depending on the species, soaking or fermentation is necessary.
- *Cucurbita. pepo*: If the fruit is bitter, it is poisonous, do not eat or reproduce it!

Species		Staking	Harvesting	Treatment
Cucurbita pepo	Zuccini, Pumpkin, Squash	No	Overripe fruit	SW
Cucurbita maxima	Pumpkin, Squash	No	Ripe fruit	SW
Lagenaria siceraria	Calabash, Egusi	Yes	Dry fruit	W
Cucumis sativus	Cucumber	No	Overripe fruit (yellow)	WF
Cucumis melo	Melon	No	Ripe fruit	SW
Citrullus lanatus	Watermelon, Egusi	No	Ripe fruit	W

9.2.4 ASTERACEAE, AMARANTHACEAE, BRASSICACEAE

The cultivation for seed of the majority of species in these families is very different from productive cultivation. The parts consumed are often vegetative parts (leaves of lettuce or amaranth, cabbage, root of radish). It is therefore necessary not to consume these parts on the seed crops. The plant can then produce flowers and seeds. Harvesting is done just before the seeds are fully ripe, before they fall out by themselves and are lost. It is important to protect these seed crops from rain, otherwise the entire crop may be lost. The seeds should be crushed regularly between the fingers. If the seeds come out of the pods easily, it is time to harvest.

When they are mature, they turn brown. The whole plant or part of it is harvested, dried and then threshed into a bag. If the whole plant is not harvested, only the ripe parts are harvested. For species where the leaves are usually harvested, much more space is needed for the seed crop, which can grow much larger.

Reproduction: Cross-pollinated (insects), except Amarante (wind)

Number of seed holders required: 10-15

Shelf life: 4

Specie		Crop		Harvest		Post-harvest	
		Wet season	Staking	Part	Nbr	Threshing	Seed per plants
Helianthus annuus	Sunflower	No	No	Head	1	Easy	
Amaranthus species	Amaranth, Celosia	No	No	Plant	1	Easy	30 g
Brassica oleraceae	Cauliflower, Brocoli, Cabbage	Depends on varieties	Yes	Pods	Several	Sensitive	1000-2000
Raphanus sativus	Raddish	Depends on varieties	Yes	Pods	Several	Sensitive	1000-2000

9.5.4 SPECIAL CASE: LETTUCE (*LACTUVA SATIVA*)

The collection of lettuce seeds is very difficult and is therefore precisely described.

Reproduction: Self-pollinated, Hermaphrodite Number of seed crops: 10

Number of seeds per crop: 10 g

Shelf life: 3

Staking: Yes

If you do not harvest the leaves of the lettuce, it will grow, produce flowers and seeds. It is important to provide plenty of room for the seed crop, which will become very large (50-60 cm apart). Staking is essential as well as protection from rain. The seeds are ready for harvesting 12-25 days after flowering, when 50-70 % of the flowers are in plumes. The finger test mentioned above can help determine the right time. Then shake the plants over a container. Harvest 2-3 times at intervals of a few days. Do not mix the batches, as the seed from the first harvest will be of better quality. Finally, cut and thresh the plants into bags. Threshing should be done gently as the seeds are fragile. Cleaning with sieves is almost essential, as more than half of the harvest is not actually seed and may contain diseases.

9.5.5 ONION AND CARROT

Onions and carrots have in common that the seed production is done in 2 separate crops:

- 1st crop: bulb and root production from seed.
- 2nd crop, seed production from bulbs and roots.

The production goes as follows:

- When harvesting carrots and onions, 50-60 carrots and 40-50 onions are selected. They should not be damaged and should correspond to the size and shape of the variety. Ideally, the spring harvest should be used for this selection.
- The onions are then stored under cover of rain and sun (as for yams) during the rainy season. Every fortnight, rotten bulbs should be removed. Check that the species does not need vernalisation.
- Carrots are stored in desert fridges. Cut off the leaves up to 2-3 cm, do not damage the core of the carrot. Remove rotten carrots regularly.
- In autumn, at the end of the wet season, 30 carrots and 20 onions are selected for planting. It is advisable to grow the seedlings in the dry season to avoid the risk of rotting.
- The storage stage is not necessary for varieties that do not require vernalisation. Growing in spring and autumn avoids growing seed crops in the rainy season.
- Protect crops from rain, install stakes.
- Cut the seed umbels when they are mature (brown). Harvest as you go.
- Dry and then thresh. Threshing is difficult, the seeds do not come out of the bolls easily.

Carrot seeds

	Carrot (*Daucus carota*)	Onion (*Allium cepa*)
Family	Apiaceae	Alliaceae
Reproduction	Cross-pollinated (insects)	Cross-pollinated (insects)
Flower	Monoecious	Hermaphrodite
Spacing of seed crop	20 cm x 40 cm	15 cm x 25 cm
Drying time of umbels	2-3 weeks	1 week
Nbr of seeds per crop	0,25 g	4 g

9.5.6 GRASSES

Reproduction: self-pollinated, hermaphrodite (except maize: cross-pollinated, monoecious)

Number of seed crops required: 100-150

Shelf life: 3

Seed crops are cultivated the same way as the food crop. Just before harvesting, when the seeds are mature (dry seeds, brown and dry leaves), spikes should be harvested from healthy, large plants that produce many seeds. It is important to collect seeds from 100 to 150 plants, although not all the seeds should be collected. Do not harvest unripe seeds. The cobs are then dried for 2-3 weeks in a dry, aerated place. Maize is harvested with the husk leaves, which are turned over to hang the cobs during drying. After drying, the cobs are threshed in bags (in the case of maize, they must be rubbed by hand). It is not necessary to remove the husks from the grains. Before sowing, soak the seeds in water. Floating seeds are not suitable.

Forage species are grown in the same way. However, since these species are often used for their leaf production, they should be given more time without mowing to produce seed. In general, vegetative propagation is more suitable for fodder grasses.

9.5.7 LEGUMES

Reproduction: cross-pollinated (insect), hermaphrodite (except soybean and pea: self-pollinated)

Number of seed holders required: 15-20 (pois: 50)

Shelf life: 3

The cultivation of the seed crop is carried out in the same way as the production crop. Allow the first 2 to 3 pods of 15 to 20 plants to dry. Harvest the pods when they are dry and mature (colour change). Dry for 2-3 weeks and then gently thresh. In the case of soybeans, the whole plant is harvested, dried and threshed.

For fodder legumes where the plant is harvested at maturity (mucuna, pigeon pea), the process is identical. For legumes whose biomass is mainly harvested before maturity (stylosanthes, desmodium), it is important to leave part of the field to produce seeds, protecting it from mowing and animals. The stylosanthes seeds are harvested as you go, as the plants do not mature simultaneously. It is not necessary to remove the seed coats.

9.5.8 TREES

Grain trees: Leguminous trees (Gliricidia, Leucaena, Acacia, Cajanus etc.) produce bean-like pods. Harvesting can therefore be done in a similar way to that of grain legumes such as beans. The pod is allowed to mature and dry on the tree. It is picked before it opens, dried and gently threshed. The seeds are then used to prepare tree seedlings for the following seasons. Some species that are not legumes but produce similar seeds can be treated in the same way (Moringa, Neem).

Pawpaw: It is very easy to collect the seeds of the pawpaw that are inside the fruit. The seeds should be dried and then stored like any other plant seed. The seeds are then planted in pots. The pawpaw is a dioecious plant, there are male, female and hermaphrodite plants. Since male plants do not bear fruit, only females and hermaphrodites should be transplanted to the field. Identify the male flowers and remove the plants.

Other fruit trees: This document does not explain how to propagate fruit trees (mango, avocado, citrus, etc.). Most fruit trees do not need to be propagated regularly because they produce for decades. In addition, propagation is complicated and requires experience to produce quality plants. It is therefore advisable to rely on local nurseries and to buy plants that are a few years old when a new fruit tree is to be planted

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Agroecology, a science and agriculture practice for small-scale farmers in sub-Saharan Africa

This document is aimed at agronomists and producers who are already suitably trained in the management and understanding of conventional or organic production systems. It addresses the basics of ecology, chemistry and agronomy necessary to understand agroecological practices. It describes these practices and how they work. After going through this document, the reader will be able to establish, develop and manage a sustainable productive agro-ecosystem: an ecosystem capable of producing without inputs and without depleting its resources.

Covered topics:

- Introduction
- Soil Fertility
- Soil Protection
- Fertilisation
- Water Management
- Pest Management
- Crop Associations
- Livestock in Agroecology
- Seed Collection and Conservation

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